DOCUMENT RESUME

ED 309 075 SE 050 729

AUTHOR Amidei, Rosemary
TITLE Sea Grant in California: Twenty Years of Achievement.
INSTITUTION California Univ., La Jolla. Sea Grant Coll. Program.
SPONS AGENCY National Oceanic and Atmospheric Administration (DOC), Rockville, Md. National Sea Grant Program.
REPORT NO R-CSGCP-026
PUB DATE 89
GRANT NA85AA-D-00140
NOTE 82p.; Drawings may not reproduce well.
AVAILABLE FROM California Sea Grant College Program, University of California A-032, La Jolla, CA 92093-0232 (single copies free while supply lasts).
PUB TYPE Reports - Descriptive (141) -- Historical Materials (060)

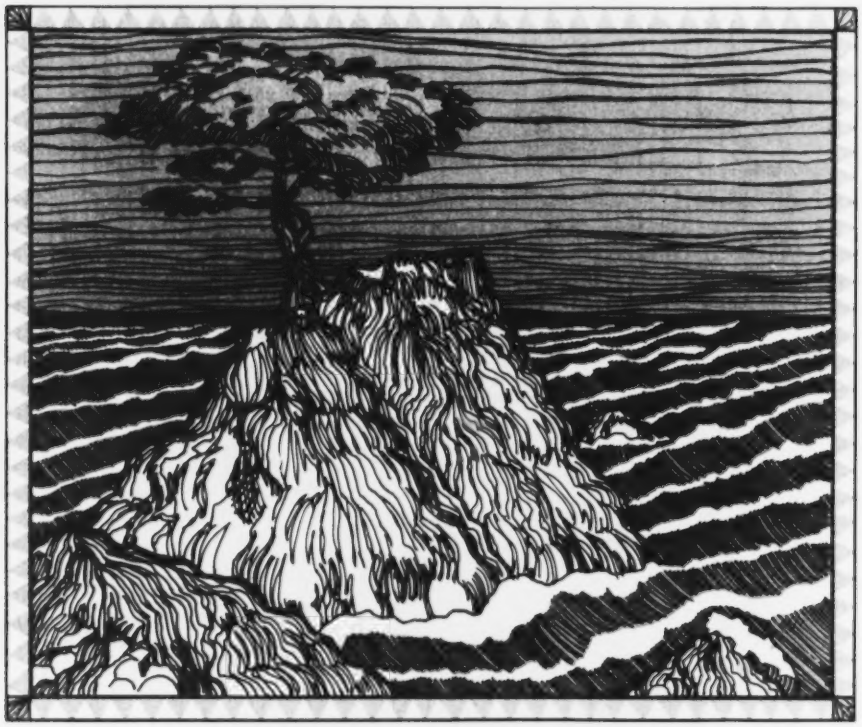
EDRS PRICE MF01/PC04 Plus Postage.
DESCRIPTORS Animals; Conservation (Environment); *Educational History; *Environmental Education; Extension Education; Financial Support; Fisheries; *Government Role; Higher Education; Ichthyology; Marine Biology; *Marine Education; Natural Resources; Oceanography; *Program Descriptions; *Research Universities; Science Education
IDENTIFIERS *Sea Grant Program

ABSTRACT

Since 1968, the California Sea Grant program has operated to produce scientific research oriented to solving problems in marine resource development, management, and conservation. This document decribes the facets of this program, their accomplishments and goals. Discussions include: (1) historical notes; (2) coastal governance; (3) coastal wetlands; (4) coastal physical processes; (5) fisheries; (6) aquaculture; (7) anadromous fishes; (8) crustaceans; (9) mollusks; (10) new products from the sea; (11) ocean engineering; (12) offshore structure safety; (13) the extension program; and (14) education. Participants in several sea grant committees, fiscal data, personnel data, and institutions which participate in the California Sea Grant Program are listed. (CW)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED309075



SEA GRANT IN CALIFORNIA

Twenty Years of Achievement

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

• Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

Lindy Nagata

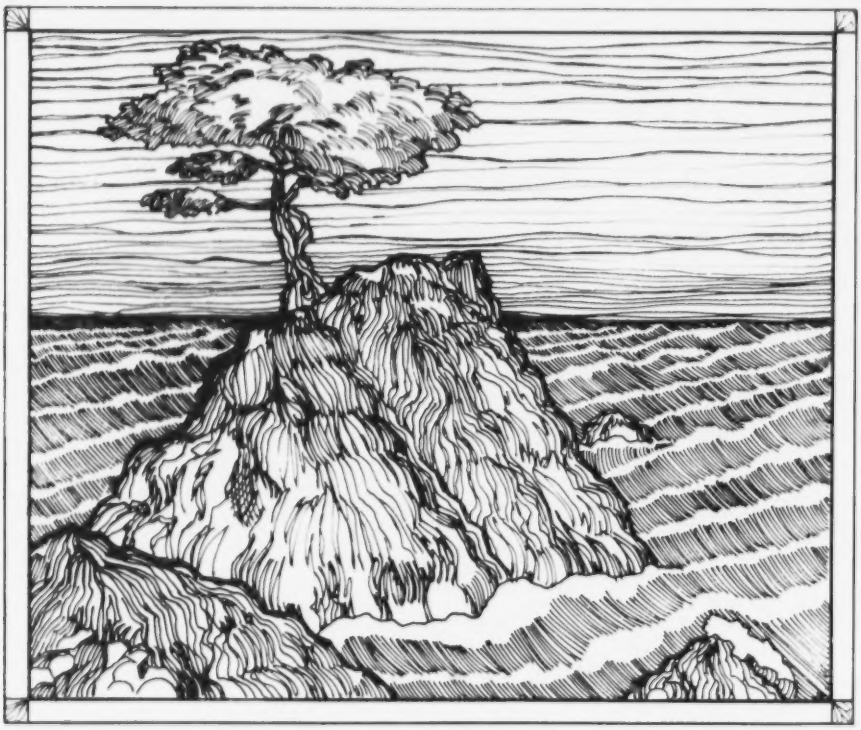
TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

SE 050 129

Rosemary Amidei
Communications Coordinator

Published by the California Sea Grant College Program, University of California,
La Jolla, 1989. Additional single copies are available free of charge from: California Sea Grant College Program, University of California, A-032, La Jolla, CA 92093-0232.
Phone (619) 534-4444.

We gratefully acknowledge the assistance of NOAA, National Sea Grant College Program, Department of Commerce, under grant NA85AA-D-00140, Project #A/P-1 and of the California State Resources Agency. The U.S. Government is authorized to produce and distribute reprints for governmental purposes.



SEA GRANT IN CALIFORNIA

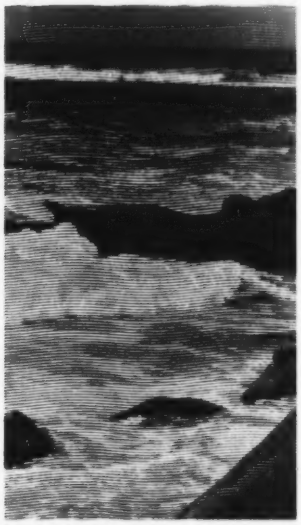
Twenty Years of Achievement

California Sea Grant
College Program
University of California
La Jolla, California 92093
Publication No. R-CSGCP-026

Table of Contents

Introduction	4
California Sea Grant: The Formative Years	7
Sea Grant: Contributing to Wise Coastal Governance	11
The Functioning and Manipulation of Pacific Coastal Wetlands	15
Physical Processes in the Coastal Zone	19
Fisheries and Aquaculture in California: A Retrospective	24
Research into California's Diverse Fisheries	27
Culturing Anadromous Fishes	30
Developing Centers for Crustacean Research	35
Molluscan Aquaculture: Providing Gourmet Fare	38
Investigating the Ocean's Potential to Yield New Products	43
Ocean Engineering Under California Sea Grant	47
Improving Technology for Working in the Oceans	51
Enhancing the Safety of Offshore Structures	55
The California Sea Grant Extension Program	57
Education—A Commitment to the Future	70
Committees	72
Fiscal and Administrative Data	75
California's Sea Grant Institutions	80

Introduction



On October 25, 1973, at an awards ceremony held at the University of California, Berkeley, then-President Charles J. Hitch accepted a plaque from National Oceanic and Atmospheric Administration Administrator Robert White on behalf of the Secretary of the U.S. Department of Commerce, designating the University of California as a Sea Grant College.

In his remarks, President Hitch compared the importance of the event in University history to that of its designation as a land-grant college and remarked:

The sea never changes, but man does, and the Sea Grant program is indicative of a new, more serious, and more respectful approach to fathoming the mystery. I am proud that in this the University of California will play a major role.

The University's selection as a Sea Grant College was based on its record of achievement in marine-related research, education, and advisory services since the first Sea Grant award was made to UC San Diego in 1968.

Today, some two decades after the beginning of Sea Grant in California and 16 years after the University of California's designation as a Sea Grant College, we are in a position to look back over the program's achievements, for it is these achievements that will form the basis for the University's recertification as a Sea Grant College. The timing for such a review is, of course, opportune, for we live in an age of rapidly expanding consciousness about the importance of the oceans and our impact on them.

The University's Sea Grant College Program has a strong record of productive scientific research oriented to solving problems in marine resource development, management, and conservation. Over 1,000 articles have appeared in the scientific and technical literature as a result of the work supported by this program, and hundreds of conference reports, books, and other documents have been published. This research has been done not only by scientists at the nine campuses of the University of California but also by researchers from the California State University System and other California institutions of higher learning.

California Sea Grant has become a model for fostering communication and collaboration among the educational, governmental, and private sectors. In this regard, Sea Grant's marine advisors and specialists, housed within the University of California Cooperative Extension, merit special mention. They have played a particularly important role in facilitating the flow of information between the broader marine community and university-based researchers.

In addition to its research and extension activities, Sea Grant contributes to the national good through its support of education—and particularly graduate education.

We tend to lose sight of the fact that investment in higher education produces cultural and economic returns to society, in addition to enhancing the nation's competitive standing in the world economy. The California Sea Grant Program can be proud of having supported over 600 graduate students in fields as diverse as oceanography, engineering, geology, law, and food science. Of these, over half (57%) were awarded doctorates and 42% have earned master's degrees.

Sea Grant today remains an innovative program that fills a unique niche in American marine science. Its application-oriented research, its interdisciplinary perspective, and its emphasis on information transfer and education, all contribute to the University's ability to fulfill its essential mandate to society.

William R. Frazer
Senior Vice President–Academic Affairs
University of California

Admiring the plaque designating the University of California as a Sea Grant College in this 1973 photo were (left to right): Jeffery D. Frautschy, George G. Shor, Jr., John D. Isaacs, William A. Nierenberg, and James J. Sullivan, prominent University and Sea Grant administrators involved in California Sea Grant's early development.

California Sea Grant: The Formative Years

With the signing into law in 1966 of the Pell-Rogers Sea Grant College and Program Act by President Lyndon Johnson, the nation's Sea Grant Program was created. Its objective, to accelerate the development of the nation's ocean and coastal resources, explicitly included not only resource assessment, development, and utilization, but also conservation.

The name "Sea Grant" was chosen to emphasize the program's similarities to the century-old "land grant" college program in its orientation to national economic development through the involvement of higher education. Like land grant, Sea Grant sought to promote close relations between academic, governmental, and industrial institutions, and like land grant it conducted research, education, and extension activities in support of its aims.

Originally assigned to the National Science Foundation, Sea Grant was transferred to the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce in 1970 when NOAA was established by Executive Order. Today, the National Sea Grant College Program comprises 30 state programs that conduct activities in marine science and technology at more than 300 universities and affiliated institutions.

In California, Sea Grant began in 1968 with an award to the Scripps Institution of Oceanography, part of the University of California, San Diego (UCSD), to develop an interdepartmental, graduate-level curriculum in Applied Ocean Science. Even getting that far required the effort of far-seeing individuals. As UCSD Chancellor John S. Galbraith wrote to the then-acting president of the University:

Applied oceanography of the type envisaged in the Sea Grant College bill is not currently the thrust of Scripps research, although the Institution and certain campus departments possess considerable talent which might be utilized for such a program. The basic question is whether the State is willing to provide the additional resources necessary for Scripps to mount such a program.

That the University was willing to make the commitment was shown by a resolution of the Regents on December 1, 1967, to provide two-thirds of the salaries for instructional faculty appointments to the proposed curriculum project.

By the following year, the National Sea Grant Program was supporting separate projects as well at San Diego State University (SDSU) and UC Santa Barbara.

Shortly thereafter, the programs at Scripps and SDSU joined to establish an institutional program. And in 1971, at the request of UC President Charles J. Hitch, the University of California as a single statewide institution was designated a Sea Grant Institution, with responsibility for its management fixed in the Office of the President.

The designation Sea Grant College symbolizes a mutual recognition of continuing responsibility, both by the Department of Commerce and the institution so designated, to develop and maintain the excellence and public utility of the institution's Sea Grant program.

At that time, UC President Hitch appointed a Sea Grant Coordinating Council, consisting of both university and public members, to advise him on Sea Grant policy. He appointed the director of Scripps, William A. Nierenberg, to be chairman of the council and his representative in the administration of Sea Grant. Hitch assigned responsibility for coordinating the Sea Grant program to the university-wide Institute of Marine Resources (IMR), where the program was briefly under Benny Schaefer, and later under John D. Isaacs and then Fred N. Spiess.

Within IMR, the principal investigator of Scripps' Sea Grant program, George Shor, was assigned responsibility for the conduct of the program. Shor directed the program until September 1973, when he was succeeded by Jeffery Frautschy. In August 1975, James J. Sullivan became director of California Sea Grant, a position he continues to hold.

During its formative years, Sea Grant's history in California was complex: at one time, there were as many as seven separate Sea Grant programs in the state. Unapologetically, and perhaps with tongue in cheek, Isaacs once wrote of the early program:

It is . . . no more and no less complex than the State of California itself, which is the highest, lowest, most populous state in the union, with the widest range of climates, the largest fishing port, the most technologically advanced fishing industry, and the largest oceanographic institution.

Ultimately, in order to achieve greater coordination and to reduce administrative expenses, programs at the various campuses of the University of California and the California State University and Colleges system consolidated into the University of California Sea Grant Program. Today, the institutional program at the University of Southern California is the only separate Sea Grant program in the state.

Under a later administrative reorganization of the IMR, the charge of the Sea Grant Coordinating Council was assigned to a reconstituted IMR Advisory Council, which continues to advise the President of the University on IMR matters, including Sea Grant.*

The year 1973 became a landmark in Sea Grant's early history with the announcement by the Department of Commerce that the University of California had been selected for designation as the nation's seventh Sea Grant College "for sustained excellence in research, education, and public service dedicated to wise use of America's marine resources." The designation involved commitments by both the Department of Commerce and the University:

The designation Sea Grant College symbolizes a mutual recognition of continuing responsibility, both by the Department of Commerce and the institution so designated, to develop and maintain the excellence and public utility of the institution's Sea Grant program.

*At the present time, the organization of IMR is under study.

By the award of Sea Grant College status, the Department of Commerce expresses its confidence in the demonstrated dedication and competence of the Sea Grant College by assigning priority of support to the College, within the limits of overall Federal priority and fiscal considerations, renewable as continued performance by the College may warrant.

*The Sea Grant College accepts with such designation the responsibility for the continued pursuit of excellence in marine research, education, and public service, through advisory programs, and the exercise of leadership in its region in assisting and supporting other institutions and agencies, both public and private, in the development of programs for the proper use and protection of the marine environment.***

Sea Grant's legislation requires that at least one-third of the total federal funds received by each program be matched with local (nonfederal) funds. Thus, a second significant event in 1973 was the enactment by the State of California of legislation to provide a half-million dollars a year for a five-year period to the Sea Grant programs of California to be used for up to two-thirds of the required local matching funds. This commitment was designed to enlarge the Sea Grant program in California and was viewed as state recognition of the usefulness of Sea Grant activities. The state government thus became a partner with the federal government and with California's great university systems in the Sea Grant program. This commitment was renewed by legislation in 1978 and 1983, and most recently in 1988 at a level of $525,000.

The 1973 legislation, authored by State Senator John Stull, also created the Resources Agency Sea Grant Advisory Panel (RASGAP), whose members are appointed by the state's Secretary for Resources. The goal of the RASGAP is to select only those projects for state-matching support that have a clearly defined benefit to the people of California. RASGAP meets twice yearly to review progress and establish research priorities as well as to select projects for state support.

The combination of state and federal funds made the University of California program the largest Sea Grant program in the nation, a distinction it continues to enjoy.

A number of early policy decisions on the program have significantly shaped it to the present day. The first and perhaps most important was that the program would be "open-ended"; that is, it would not be limited to the University of California but would be open to participation by any state or private university that wished to associate with it. This policy was adopted in order to provide the program with broad geographic coverage; access to the widest possible range of talents, interests, and facilities; and the local contact and support necessary for a successful Sea Grant College Program.

Other pivotal decisions were that research funds would not be

**From "The National Sea Grant Program: Program Description and Suggestions for Preparing Proposals," National Oceanic and Atmospheric Administration, 1972.

allocated on the basis of subject area quotas or quotas for specific campuses, but would be awarded instead on the scientific merit of submitted proposals and their relevance to Sea Grant's mission. This decision committed the program to an extensive, merit-based process of internal and external proposal review in which the Sea Grant director is assisted by the California Sea Grant Committee. This committee, which also provides guidance in the development of program policy, presently includes eight faculty members from campuses of the University of California, three from the California State University system, and one from the University of Southern California.

The initiation of Subject Area Meetings provided an important tool in developing program direction by allowing representatives from all interested campuses, plus government and industry representatives, to engage in fruitful dialogue on ongoing work and future needs.

From the beginning, California Sea Grant's application-oriented focus made it multidisciplinary in approach and allied it in partnership programs with government and industry. These partnerships are maintained and strengthened by a variety of mechanisms, notable among which are joint projects, industry advisory committees, communications programs, and the outreach activities provided by its extension services to a wide variety of client groups.

Sea Grant is a successful model for university/industry/government cooperation. It has contributed and will continue to contribute to the competitiveness of the nation's economy, to the pool of skilled manpower, to scientific achievement, to technology transfer, and to public education on critical resource and environmental issues.

Sea Grant: Contributing to Wise Coastal Governance

In November 1972, after several failed attempts in the legislature (the earliest led by now-U.S. Senator Pete Wilson), California voters enacted a revolutionary ballot initiative that put the state ahead of its time in its commitment to achieve comprehensive statewide planning of the coastal zone.

This landmark statute, the California Coastal Zone Conservation Act of 1972, reflected the public's strong environmental sentiments and its realization that the complex and fragmented management system that had evolved (split up among 15 counties, 45 cities, 42 state units, and 70 federal agencies) could not protect the coast against the relentless pressures of population growth and shoreline development.

By the early 1970s, California's population exceeded 20 million—triple what it had been at the outbreak of the Second World War 30 years earlier. Half the population resided in the state's three southernmost counties (Los Angeles, Orange, and San Diego counties), and 85 percent lived within 30 miles of the coast. Despite the historic concept of the shore as a public trust, the coast was being developed for homes, ports, industries, freeways, refineries, and a host of other uses. By the early 1970s, only 260 miles of California's 1,100-mile shoreline remained accessible to the public.

It had traditionally been assumed that coastal zone problems were strictly local and could be solved by "tide pool" scientists.

The statute enacted in 1972 created the California Coastal Zone Conservation Commission and six regional commissions. It directed these bodies to prepare a statewide "comprehensive . . . enforceable plan for the orderly, long-range conservation and management of the coastal zone . . . ." The plan, which was to be completed and adopted by the state-level Coastal Commission no later than December 1, 1975, was to be based upon "detailed studies of all the factors that significantly affect the coastal zone" and was to recommend the organization and authority of the governmental agency or agencies that would carry it out. Further, during the planning period, the commissions were directed to regulate development in coastal waters and in a 1,000-yard shoreline permit area that was extended in specified critical areas.

Though Sea Grant was supportive of the Act's aims of coastal protection and wise management, program leaders recognized that there was a dearth of relevant scientific information and understood that lack of fundamental understanding of physical and biological processes in the coastal zone would hinder promulgation of effective policies for managing natural resources. A Sea Grant proposal from that period makes the point that though coastal processes are in fact more complex than deep-ocean processes, "research in the nearshore or coastal zone has lagged behind that in the deep sea because it has traditionally been assumed that coastal zone problems were strictly local and could be solved by tide-pool scientists." In addition, because California was a leader in designing a comprehensive management scheme, there was

little information available on the policy aspects of coastal planning.

Thus, from the early 1970s, California Sea Grant supported a three-pronged effort in its Coastal Resources subject area. Two elements addressed the basic sciences—physical and biological—needed to provide wise management of the coastal zone (these efforts will be described in more detail in later reports). The third element of Sea Grant's work in Coastal Resources—namely, public policy—was particularly strong in the 1970s as commission staffs and later the state legislature geared up to meet the citizen mandate.

In 1971, with Sea Grant support, Robert H. Twiss, an associate professor of environmental planning at UC Berkeley, undertook the development of a system for reconciling competing interests in the coastal zone. Associated with this project, and later heading a number of related projects, were three social scientists: Ira Michael Heyman, a research lawyer with the Institute of Urban and Regional Development at UC Berkeley, and Thomas Dickert and Jens Sorenson, both research planners with that institute. They were, with Twiss, to form the core of Sea Grant's early efforts to provide support and guidance to the state as it undertook its planning effort to balance coastal conservation and development.

Involvement of these researchers with the state-level Coastal Commission dated from shortly after the organization of its planning staff in February 1973, and one of their first activities was to help the staff to clarify and redefine the planning requirements set forth in the Act. The policy issues were thorny and emotion-laden. Gerald Bowden of UC Santa Cruz, who analyzed relevant legal issues as part of a Sea Grant project, described the two most extreme points of view this way:

For some Californians, the remaining bits of undeveloped coastline are what they were to the London club man: "A damp sort of place where all sorts of birds fly about uncooked." But an astonishing number of persons regard these remaining bluffs, canyons, and dunes with something like religious reverence.

How, in fact, could the developer, the beachgoer, the fisherman, and the conservationist coexist? Could a valuable coastal habitat with its assemblage of native plants and animals be preserved? Were there realistic opportunities for restoration? How should the coast and its resources be managed and by whom? What valuation should be put on the scenic aspects of the coast? By what means could the public acquire selected properties, and what would be the economic impacts? How could the public's constitutional right of access to the ocean's edge be assured? The list of issues went on and on.

One notable activity of the Sea Grant research team was to develop and test a step-by-step process that could be used by local units of government to prepare coastal plans in conformance with policies

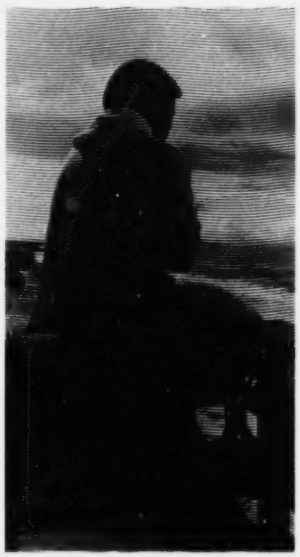
adopted by the state Commission. They used the Half Moon Bay area as a case study to test the applicability of many key Coastal Commission policies, several of which were later revised on the basis of problems revealed by the study. The Sea Grant researchers were also able to place two half-time trainees at the Coastal Commission where they worked closely with the staff. In addition, the researchers built up a library of over 2,000 documents on coastal zone management and planning, which over the years has been widely used by Commission staff, students, and a variety of special-interest groups. The Sea Grant staff also assisted the Water Research Center Library at Berkeley in collecting minutes of all Regional State Commission meetings—perhaps the only generally accessible collection of these documents.

In 1973-74, with Sea Grant support, Eugene Lee and Stanley Scott of the Institute of Governmental Studies at UC Berkeley began to look at alternative organizational arrangements for long-range coastal management. In the course of their work as consultants to the staff of the Coastal Commission (and at its request), Scott prepared a comprehensive description of the state and regional commissions and their effectiveness. His study was published in 1975 by the Institute of Governmental Studies under the title *Governing California's Coast*. In addition, Lee and Scott collected information about coastal planning and land-use control elsewhere in the country and prepared a report on the California experiment in coastal governance for the benefit of other states.

With the delivery of the California Coastal Plan to the state legislature in 1975, Sea Grant began a major new effort to provide assistance to the legislature through a series of rapid response projects.

Meanwhile, one of the important future areas of Sea Grant research was being set as a result of the appointment of Jeffery Frautschy, an assistant director of Scripps, as Sea Grant program manager. Frautschy, named program manager in September 1973, was also a member of the state Coastal Zone Conservation Commission on which he represented the San Diego Coast Regional Commission. As a result of these involvements, Frautschy came to know what scientific information was most badly needed by policy makers.

California's fast-disappearing wetlands were a particular frustration to him. Nearly 70 percent of the state's total wetland and estuary area had been lost to development since the turn of the century, but virtually nothing was known about these ecosystems on the West Coast. So, at Frautschy's direction, Sea Grant's 1974 Call for Proposals specifically invited proposals related to wetlands. The result, beginning in 1976, was a major Sea Grant emphasis on wetlands research that continues to this day. As will be described in a later report, this area of research clearly demonstrated that California estuaries were functioning



differently from their counterparts on the East Coast and the Gulf Coast. Furthermore, these differences stimulated additional Sea Grant studies on the East and Gulf coasts, which demonstrated that many of the then-held "truths" were in error. In retrospect, it is now clear that research supported by California Sea Grant has had a national impact and led to better understanding of these environments nationwide.

As a member of the Coastal Commission, Frautschy was also impressed with the implications of work by Scripps' scientists Francis Shephard and Gerald Kuhn on the erosion of coastal cliffs and bluffs—particularly since the conventional wisdom, that California's seacliffs showed no appreciable erosion, had led local agencies to permit construction of buildings within just a few feet of the edge. He later accompanied Kuhn on trips up and down the state to speak about seacliff fragility to more than 100 community groups.

These observations served to re-emphasize the interactions between the sea and the land, and California Sea Grant has continued to pursue an active program in the study of coastal processes.

Finally, in September 1976, the governor signed legislative reaffirmation of the citizens' 1972 initiative, creating a permanent coastal zone management authority and establishing a system of state and local collaborative planning. California Sea Grant's extension personnel worked closely with coastal planners in the development of local plans.

Meanwhile, implementation of the federal Coastal Zone Management Act was proceeding in California and other states, giving continuing impetus to California's efforts. These developments continued to be documented by Lee and Scott, who observed that by virtue of the state's involvement in coastal planning, "all governmental levels of our federal system may be learning to work together in ways they have not really attempted before."

This theme of "learning to work together in new ways" was to continue to be important in the 1980s, though in relation to very new policy issues. Working within the newly evolved Sea Grant subject area of Marine Affairs, Biliana Cicin-Sain of UC Santa Barbara has explored bilateral relations between the United States and Mexico in relation to marine resources such as tuna (this with Michael Orbach of UC Santa Cruz); the challenges to local and state government posed by federal development of offshore oil and gas reserves; and, most recently, California's role in planning for the development and protection of marine resources within the Exclusive Economic Zone. Given revived interest by the state in achieving comprehensive management of marine resources, it is likely that public policy will continue to be a vital concern of California Sea Grant.

The Functioning and Manipulation of Pacific Coastal Wetlands

It is an understatement to say that studies of Pacific coastal wetlands have lagged behind those of the Atlantic and Gulf coasts. Comprehensive studies of East Coast wetlands date back to the 1950s. But until 1976, just 13 years ago, there was no coordinated program of investigation of the West Coast, although isolated studies had begun to lay the groundwork for later Sea Grant research.

Much of the disparity in research effort between the eastern and western coasts of North America is founded in geography. The expansive coastal wetlands of the Atlantic did in fact warrant far greater attention than the tiny, isolated units of the rugged Pacific Coast. Unfortunately, the very real differences between ecosystems on the two continental edges were overlooked or deliberately ignored when facts about Pacific wetland functions were needed. It was simply assumed, for example, that the impact of disturbing a California salt marsh could be extrapolated from work done in Georgia.

Sea Grant challenged the premise that coastal wetlands on the East and West coasts functioned similarly.

The California Sea Grant College Program began its study of coastal wetlands by challenging the premise that the eastern and western systems functioned similarly. On the basis of the reasoning that the West Coast's smaller watersheds, its smaller floodplains and intertidal areas, and its more variable rainfall and streamflow inputs would produce differences in the resulting coastal ecosystems, two estuarine studies were initiated in 1976 in Southern California. Although their projects were independently conceived, researchers were encouraged to interact, and so a long-term collaboration grew out of the programs at UC Santa Barbara and San Diego State University.

The extensive work done at Mugu Lagoon by Robert Holmes and Christopher Onuf of UC Santa Barbara remains impressive, the result being a detailed understanding of algal and vascular plant productivity, benthic macroinvertebrate communities, fish population dynamics, and predator-prey interactions among birds and invertebrates at this small, but continuously tidal system. The information was later summarized by Onuf in an estuarine profile for the U.S. Fish and Wildlife Service. In addition, the results were widely reported in the ecological literature, and several theses and degrees were earned by graduate trainees.

At San Diego State University, similar studies by Joy Zedler and David Mauriello focused on the Tijuana Estuary, but with comparisons at less frequently tidal or nontidal marshes nearby and with an emphasis on the effects of disturbance (especially reduced tidal flushing). A community profile on regional salt marshes resulted, along with theses, degrees, and scientific literature, and eventually Zedler and Nordby's estuarine profile, T*he Ecology of Tijuana Estuary, California*, jointly published by the U.S. Fish and Wildlife Service and California Sea Grant.

The result of these first investigations of ecosystem functioning

was clear—Pacific wetlands were very different from their eastern counterparts, for reasons of hydrology and area. Onuf and associated investigators at UC Santa Barbara summarized the situation at a national conference on coastal wetlands: primary productivity in West Coast wetlands is not as impressive on a per-area or total coastline basis as in the East, nor is the commercial fishery as dependent on the outwelling of foods from rich estuarine systems. There are, however, unique habitat values in the western marshes that are essential to native plants and animals threatened with extinction.

An unexpected bonus of both projects was that data gathering began just before several extreme events occurred in the region, including major floods in 1978 and 1980. Both research teams took advantage of their unique preflood studies to develop long-term data sets that have become the envy of researchers elsewhere. At Tijuana Estuary, systematic sampling continues, with 10 years of comparable information, encompassing both flood and drought conditions, open and closed inlets, cold and mild winters, years with and without renegade sewage flows, and years with and without major dredging events.

While California Sea Grant provided the impetus for the long-term data sets, it was not burdened with long-term funding. In 1982, NOAA set aside Tijuana Estuary as one of 15 National Estuarine Research Reserves and continued the program of study. The work at Mugu Lagoon continued for five years, after which researchers took their talents to the U.S. Fish and Wildlife Service and to universities elsewhere.

The first Sea Grant studies were contemporary with the 1976 California Coastal Act, which set up a lengthy review process for development projects proposed for the coastal zone. Fortunately, the involvement of Jeff Frautschy of UCSD's Scripps Institution of Oceanography, both as a scientist and a coastal commissioner, helped ensure that new information provided by California Sea Grant was used in the planning and regulatory processes. Work done at UC Berkeley by Thomas Dickert and his colleagues generated an understanding of linkages between an estuary and its watershed. And associated projects were funded at Scripps (Douglas Inman and Charles Nordstrom) and at San Diego State University (Howard Chang and Douglas Stow) to help solve critical management problems in Pacific wetlands, for example, that small lagoons tend to close to tidal flushing, become stagnant, and decline in aesthetic appeal.

Following the initial characterizations of regional estuaries, interest moved to the issues of manipulation and mitigation. Because they harbored several endangered species whose habitat was jeopardized by further development, California's salt marshes were hotbeds of controversy. Both state and federal laws required that

damage to sensitive habitats, as well as to endangered species, be mitigated—that is, avoided, lessened, or repaired. Studies by Zedler of how to restore coastal wetlands resulted in a restoration guidebook that Sea Grant published in 1984. Like earlier research on damaged dunes by Michael Barbour of UC Davis, the California salt marsh revegetation studies built on Sea Grant-funded work done on the Atlantic Coast.

Because of increasing human modification of river flow, hydrological considerations continued to drive the research program. In Southern California there is usually little surface water flow in streams and rivers, especially in summer. Thus, enormous changes can occur in a wetland if waters from dammed rivers are discharged out of season. As an example, a salt marsh became converted to a cattail-dominated wetland in just one year as a result of water management practices. An analysis by Zedler and colleagues of how estuarine ecosystems respond to increased stream flow helped scientists and managers to understand the patterns, and provided the groundwork for regional planning for modified streamflows. The Sea Grant work is now being used to set standards for maximum freshwater discharge to Southern California's coastal streams.

Having answered the questions of what West Coast wetlands are like, how they respond to disturbance, how they can be restored, and how they respond to modified hydrology, the next logical step for Sea Grant was suggested by a national controversy over the mitigation process. Throughout the country, wetlands are known to be critical functional ecosystems, but destruction continues under the assumption that what is lost in one spot can be replaced somewhere else. But resource managers are unconvinced, and serious challenges to the practice of mitigation have developed. In San Diego Bay, litigation held up freeway construction while environmentalists and federal agencies battled. In a landmark decision, the courts decided for the habitat and set aside a 316-acre reserve for endangered species, with clear, detailed requirements for restoration of damaged lands. Working closely with the agencies and the highway department, Zedler and her colleagues are now assessing ecosystem functions and seeking understanding of the reasons for slow or ineffective restoration. The close coordination of research and management appears to be working well. A protocol for assessing how well artificial wetlands function is underway at the same time that reference data sets and scientific understanding are developing.

Elsewhere in California, and particularly in San Francisco Bay (the state's largest estuary), much of the research has been funded by other agencies, though the Bay Conservation and Development Commission has benefited from Sea Grant's research, and studies at Bolinas Lagoon have built on work in Southern California. In 1982, Sea Grant funded a major workshop at California State University, Hayward, the spin-off of

which was increased collaboration between scientists from the northern and southern parts of the state. In addition, Michael Josselyn of San Francisco State University and Randall Alberte of the Office of Naval Research are conducting studies on seagrass revegetation. Ed Melvin, the Sea Grant marine advisor for Monterey and Santa Cruz counties, has been active in wetland restoration projects at Elkhorn Slough and continues to serve on a committee that is advisory to the California Department of Fish and Game.

State and federal agencies have followed California Sea Grant's research closely, using the literature and direct access to researchers to great advantage, and several of the state's coastal wetlands now have individual enhancement plans. The influence goes well beyond the state and nation, to collaborators from Australia, England, and Mexico.

The coastal wetlands of California are subjects of major land use conflicts and controversies. The wetlands are unique, but understandable. They are dynamic and sensitive to modification. Their restoration is under way, and criteria for success are now being clarified. Thanks to the California Sea Grant College Program, a network of individuals and a substantial base of knowledge have developed in a little over a decade.

Physical Processes in the Coastal Zone

Where the ocean meets the land, there is a zone of complex interactions among a number of physical processes involving waves, tides, currents, river runoff, and eroded sediments from the land. Despite the serious and economically significant problems associated with this zone, understanding of nearshore processes remains in a rudimentary stage.

Research sponsored by California Sea Grant into coastal processes can be divided into three stages. The earliest phase, prior to 1978, was one of developing measurement techniques that would adequately define nearshore processes. The second stage, from 1978 to 1982, was an era of large-scale data gathering and model building. And, finally, there is the period stretching from 1983 to the present, in which the emphasis has turned to a series of significant coastal problems faced by California.

The first stage was marked by a strong programmatic emphasis that arose directly from the growing desire among California's citizens for state intervention into the process of coastal planning and management. Citizen concern ultimately resulted in the passage of the Coastal Zone Act of 1976.

One significant and very timely contribution to the process of coastal management was a series of Sea Grant projects conducted by Douglas Inman (and later Inman and Winant) at UCSD's Scripps Institution of Oceanography on "Physical Criteria for Coastal Planning." The project, which spanned the period 1970-1976, operated from the premise that the only rational basis for coastal planning is complete understanding of the physical processes active in the coastal environment. A further premise was that the key to describing phenomena in the coastal zone is simultaneous acquisition of data on shore processes.

In this work, a system of sensor stations was developed and attached to the ocean bottom near Scripps—for example, at the end of Scripps pier and near the head of Scripps Canyon. As many as six of these "Shelf and Shore" stations could simultaneously transmit environmental information back to a shore station, housed in a mobile van, for computer processing and analysis. Sensors, attached to each station, could be configured in different ways for different purposes and enabled the accurate measurement of such physical parameters as wave height and direction, current velocity, water temperature, and sediment transport. As part of Inman's projects, a large linear array for measuring wave direction was first used successfully, and electromagnetic current meters (used to obtain the velocities of water particles) were routinely installed in the nearshore zone. For the first time, long-term records of waves were obtained in which the directions were accurately known.

The development of this technology was a large step forward in instrumenting the nearshore waters and led to important improvements

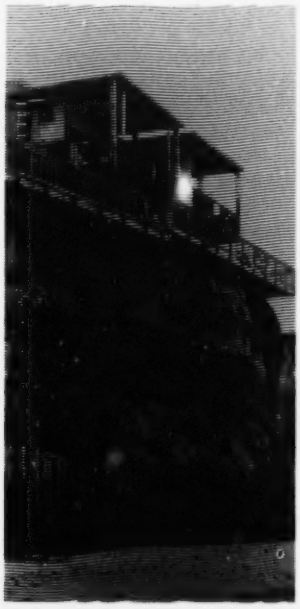
The development of this technology was a large step forward in instrumenting the nearshore waters and led to important improvements in our understanding of surf zone dynamics and shelf circulation.

in our understanding of surf zone dynamics and shelf circulation. Today, derivatives of this technology are used all over the world.

A second major program emphasis during this early period also supported coastal planning. It was the development of methodology for documenting historical trends in shoreline erosion, climate, and other factors that could help in predicting the future.

In 1977, closely following the creation of the California Coastal Commission, Francis Shepard and Gerald Kuhn of Scripps Institution of Oceanography began a series of studies designed to analyze environmental hazards in the coastal zone through geological and historical records. They explored a variety of old public records (plat maps, old land surveys, assessor tax records, aerial photographs, and Environmental Impact Statements), augmenting their research with interviews with long-term residents, old photographs, and newspaper files to present a picture of environmental change organized on important meteorological events, such as floods and storms. This, then, provided data on events that had shaped California's coastline over the past hundred years.

Shepard and Kuhn were able to document the vulnerability of California's coast to both natural forces and human impacts, showing, for example, the dangers posed to buildings sited too close to the edge of a bluff from sea-cave collapse and cliff retreat. Theirs was the first research to establish the significance of cliff erosion as a contributor to beach sand supplies. They also provided quantitative data on cliff erosion rates, and what their data showed was that erosion did not occur at some uniform, predictable rate, but rather was site specific and occurred in dramatic episodes that were frequently associated with meteorological events. A landslide in February 1978 along the cliffs at San Onofre State Park, for example, measured 700 feet long and 320 feet wide.



Also, along with Inman, Shephard and Kuhn advanced the disturbing notion that the 40-year period following World War II, during which the coastal population of California soared, was in fact a period of unusually slow erosion, characterized by low rainfall and few storms capable of producing heavy surf. (And, in fact, the destructive storms of the 1980s reinforce the notion that the postwar period was an unusually benign one.) In the late 1970s, in a major public education effort, Kuhn and Jeffery Frautschy carried the message to more than 100 community groups. Kuhn and Shephard also authored a 1981 book* on seacliff and beach erosion in San Diego County that became one of the top sellers of the University of California Press.

Another project from this period, funded by Sea Grant for just one single year, has had a significant continuing impact on coastal processes studies, both in California and elsewhere. In 1976, John D. Isaacs,

20 * *Sea Cliffs, Beaches, and Coastal Valleys of San Diego County: Some Amazing Histories and Some Horrifying Implications* by Gerald G. Kuhn and Francis P. Shepard. Berkeley: University of California Press, 1981.

director of the University of California's systemwide Institute of Marine Resources, and Richard Seymour of Scripps undertook the development of new technology for the automated measurement of the coastal wave climate, with matching support from the Department of Boating and Waterways.

The wave-measurement network that grew out of this Sea Grant project is one of the largest in the world, with stations reporting many times each day all along the California coast as well as in Hawaii, Oregon, and Washington. The network, now in its 13th year, continues to attract support from the Department of Boating and Waterways and has been continuously funded by the Army Corps of Engineers since 1978.

This program has set standards for timely reporting, availability of real-time data, and instrument reliability. One of its major accomplishments was the development of an affordable method for measuring the direction of waves in shallow water: the slope array. Long-term directional data, from which the quantity and the direction of wave-driven sand movement along the shore can be inferred, have significantly altered the coastal engineer's perceptions of these processes.

In 1978, there occurred a major exception to the modest approach to coastal processes research usually taken by Sea Grant. Though the problems associated with erosion of the coasts are everywhere recognized as serious, and though billions of dollars are spent each year on such activities as beach replenishment and harbor dredging, the conduct of significant research into coastal processes has typically been far been too expensive for the limited funds available to Sea Grant projects.

At the end of the 1970s, however, the National Office of Sea Grant received special funds from Congress for addressing problems of national importance. This created an opportunity to make greatly increased funding levels available for the study of coastal processes, thereby allowing investigators to undertake complex field studies by means of large-scale cooperative experiments.

The result was the Nearshore Sediment Transport Study (NSTS), a five-year program funded at about $1 million per year that involved six institutions from around the country** and ten principal investigators.

NSTS consisted of three major field experiments on sand transport, two of them sited in California, plus analysis of the billions of measurements made. The project was directed by Seymour, and more than half the annual budget went to investigators associated with California Sea Grant. NSTS was a unique arrangement in that the funds were administered through California Sea Grant, though funding decisions were made entirely by the National Office, with guidance

**Woods Hole Oceanographic Institution, Massachusetts Institute of Technology, University of Delaware, Scripps Institution of Oceanography (UCSD), U.S. Naval Postgraduate School, and the University of Washington.

from an external advisory board.

The result of the extensive scope of the NSTS study was the establishment of *de facto* international standards for the conduct of experiments on sediment transport in which hundreds of instruments are simultaneously deployed in the surf zone for many hours each day, measuring such parameters as water velocity, wave height, and sediment concentration.

California Sea Grant's investigators developed most of the instruments and the data-gathering systems, drawing extensively upon the experience gained in the projects earlier directed by Inman. At the completion of NSTS, therefore, they were uniquely prepared to conduct field investigations. However, the scale of the field work had been so expanded that Sea Grant could, in general, no longer afford to fund studies directed at improving our general understanding of how waves and currents move sediment and shape the shoreline. Nonetheless, the capabilities developed by the study and by NSTS have enabled other funding agencies, particularly the Office of Naval Research, to continue to support this critical research.

Further, two other major national programs in sediment transport—one in Canada and one in Japan—closely followed the inception of NSTS and adopted its model of large cooperative field experiments. The net result of these three very large coordinated efforts has been a significant improvement in our understanding of the water motions that move the sand on our beaches. In five years, our collective knowledge was advanced many times over compared with that gained during the previous one hundred years.

More recently, investigations of coastal processes have concentrated on specific problems confronting California, including sand transport, storm damage, and seismic risk. Typical of these are the studies of Howard Chang and Douglas Stow at San Diego State University on sand contributions by sporadically flowing rivers, their impacts on the coastal lagoons of Southern California, and the problems of maintaining open entrance channels between lagoons and the ocean.

The strong El Niño of 1982-83, a Pacific-wide perturbation of ocean and atmosphere, focused attention on coastal flooding associated with large waves and strong winds—a problem that will be exacerbated by even a modest rise in sea level. During this disastrous winter, over $100 million damage occurred in California alone, the result of a combination of oceanographic and meteorological factors that caused sea levels to exceed predicted high tides by as much as 60 cm at San Francisco. This led to a study by Reinhard Flick and Dan Cayan of Scripps, with matching support from Boating and Waterways, on the extent to which coastal flooding is generated by the coincidence of storm surge with high tides and other oceanographic factors. The

magnitude of the 1983 El Niño also led to a request for rapid response funds by Scripps scientists John McGowan, James Simpson, and Pearn Niiler to obtain information on the physical-chemical and biological structure of the California Current during this extreme event and by Scripps biologists Mia Tegner and Paul Dayton to study the effects of the El Niño on the population dynamics of the giant kelp.

Also needed in California is better understanding of the seismic risks associated with creating new land by dredging sand to create fill behind seawalls. A majority of the valuable facilities in the harbors of San Diego, Los Angeles, Long Beach, and San Francisco are built on such fill. Between 1982 and 1985, Iraj Noorany of San Diego State University studied methods for stabilizing fills by using mats of fibers and fabrics. He also examined the basic susceptibility of landfills to liquefaction during earthquakes, with consequent failure of structures. The work of Toyoaki Nogami of Scripps continues this program theme with further study of stabilization and improved techniques of analysis.

Other recent trends in research include basic study of the fluid-granular interface in the surf zone by Inman and his students.

Finally, Robert Lowe and Robert Guza of Scripps Institution of Oceanography have addressed the basic problem of measuring the directional characteristics of ocean waves locally, even within the surf zone, providing information that is needed for a variety of engineering applications, including harbor siting, estimating longshore sand transport, and determining the optimal orientation of breakwaters. They have thus far been successful in developing a prototype instrument that uses Doppler acoustic technology to measure wave-induced velocities at several closely spaced positions and uses these data to estimate wave direction. The instrument is being field-tested this spring.

In summary, the management of coastal processes research by California Sea Grant has adapted to meet changing needs. During the 1970s it provided badly needed technical support to the evolving discipline of coastal zone management. Then, for a five-year period during which funding was dominated by NSTS, the internal program area was greatly reduced, and California Sea Grant provided chiefly administrative support to the NSTS national initiative. And more recently, in an era of maturing coastal management methodology, the emphasis has evolved away from the basics of sediment transport and towards a series of localized, but significant, coastal problems faced by California.

Fisheries and Aquaculture in California: A Retrospective

The University has gained stature as a center of research for fisheries and aquaculture.

Off California, seasonal winds and currents combine to cause a periodic enrichment of the surface waters with deep, cold, nutrient-rich water. This rich upwelled water causes blooms of plankton that lie at the base of a food chain that ultimately supports a wide variety of invertebrates, fish, and mammals.

Nearly 50 major commercial species of finfishes are landed in California. In addition to indigenous species such as rockfish, these include migratory visitors to the California Current, notably tunas, bonito, yellowtail, swordfish, and jack mackerel. Both indigenous and seasonal visitors support significant commercial harvests and a large sportfishery. Moreover, California has historically maintained distant-water fisheries, primarily for tropical tuna.

Two-thirds of the way down the state, at Point Conception, a sharp temperature gradient divides the nearshore ocean into two regions. To the north live salmon and other cold-water animals; to the south are the tuna and other subtropical species. But the habitat boundaries for cold-water and warm-water species are continuously shifting, as are the chemical, biological, and physical characteristics of the Current itself, causing geographic shifts of stocks from year to year as well as dramatic population fluctuations over time.

Fishing also affects population levels, sometimes disastrously. Sea otters and grey whales were among the first marine animals in California to be hunted to the brink of extinction. Subsequently, many fisheries have followed a now-familiar pattern of boom and bust. In addition, pollution and habitat destruction have taken an ongoing toll.

The crash of the sardine fishery was a traumatic event in California history. In the 1930s and early 1940s, this fishery produced nearly one-quarter of all fish caught in the United States. Its virtual disappearance beginning in 1946 was to galvanize the state's legislative, industrial, and academic communities, and lead to intensive studies of the relative effects of overfishing, environmental changes, and ecological relationships that continue to this day.

By the late 1960s, when Sea Grant was getting under way, many of California's fisheries were declining, and it was becoming evident that there *are* biological limits to world fish catch—that the ocean's potential to provide food for humanity is not boundless, as many had held. Meanwhile the modern environmental movement was developing along with the understanding that wise use of resources involves legal, social, economic, and technological considerations in addition to good scientific information.

In 1965, in response to a request from the State Office of Planning, the University's Institute of Marine Resources (IMR) produced a comprehensive study of state marine resources. The study, *California and the Use of the Ocean*, identified several fisheries that were already

fully utilized, but it also pointed out a number of underutilized species in California's waters, including anchovy, jack mackerel, squid, sharks, and hake. As will be described in a later report, the development of underutilized species was to become an important focus both for researchers and marine extension personnel within California Sea Grant.

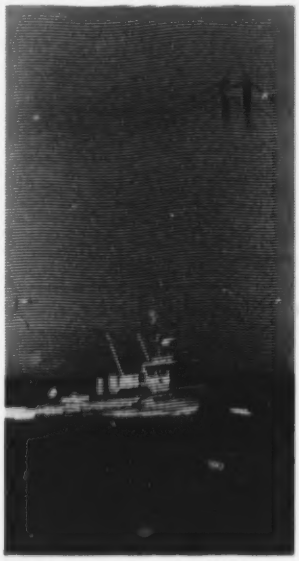
The IMR report also pointed out that effective management of fisheries requires basic biological information on exploited species and their associates. But the difficulties of studying ocean life were (and are) so great that virtually nothing was known about most marine plants and animals, including those of commercial importance.

With support from California Sea Grant, the histories of a number of California fisheries have been documented in a recent book by Arthur F. McEvoy, formerly a staff associate of Harry Scheiber (UC Berkeley). Titled *The Fisherman's Problem: Ecology and Law in the California Fisheries, 1850-1980* (Cambridge University Press, 1986), the book details the problems attendant to "common property" resources like fish (problems popularized by Garrett Hardin in *The Tragedy of the Commons*).

In contrast, aquaculture began to be viewed in the 1960s as a way by which food protein could be significantly increased. Once again, though, lack of basic biological information proved a serious handicap, particularly since marine organisms often have complex, even bizarre, life histories, and because little is known about their physical tolerances, nutrition, or diseases. Further, those geographical areas that are appropriate for farming the sea—namely, the coastal margins—are also attractive for human habitation and recreation.

Prior to 1975, the state had no planning policy for aquaculture, though oyster culture had been practiced since the early 1850s. During development of local plans as part of California's Coastal Act of 1976, however, Sea Grant's advisors and specialists worked closely with coastal planners to define aquaculture's problems and opportunities. When the state legislature enacted the California Aquaculture Development Act in 1979, it declared the activity "a coastal-dependent use that should be encouraged. . . ."

In 1975, with Sea Grant sponsorship, Gerald Bowden of UC Santa Cruz undertook a three-year study of legal issues and bureaucratic difficulties associated with California's entry into the age of marine farming. As Bowden noted, farming the sea was not merely a matter of learning to cope "with wet feet and a slippery crop," but involved creating a wholly new field of law based upon trade and commerce in domesticated plants and animals that had previously been available only in the wild. There were also numerous practical problems to be dealt with, including availability of sites, design of facilities, water quality, and a complicated permit process. Bowden was to cooperate closely



with those in the nascent industry in the development of the state's aquaculture plan.

As it happened, early research conducted in California Sea Grant's "Fisheries and Aquaculture" subject area emphasized aquaculture almost exclusively. In part, this stemmed from the rich promise seen for aquaculture, and in part it reflected the fact that no other U.S. agency was supporting work in this field.

By the mid-1970s, Sea Grant had undertaken a variety of projects in aquaculture. The successes and failures of a number of these endeavors—with lobsters, shrimp, oysters, abalone, and salmon, for example—will be described more fully in the reports that follow.

Over the years, there have been a number of changes in the University of California that trace their origins, at least in part, to the importance and visibility that California Sea Grant accorded opportunities in fisheries and aquaculture.

When the program first began, few UC academic faculty or research personnel focused their efforts on marine fisheries or aquaculture. Similarly, UC Cooperative Extension had neither advisory personnel nor specialists focused on the sea's potential. However, in large part as a result of Sea Grant's research and extension work, and with the full support of the California legislature, the University has gained stature as a center of research for fisheries and aquaculture. The small aquaculture program that was organized at UC Davis in 1977 has broadened to become a Fisheries and Aquaculture Program, and a building dedicated solely to research in fisheries and aquaculture has been constructed at the Bodega Marine Laboratory. At present, California Sea Grant is supporting research in fisheries and aquaculture at various campuses of the University of California and the California State University system, and it is involving as well project leaders from the California Department of Fish and Game and the National Marine Fisheries Service.

Research into California's Diverse Fisheries

California's thousand-mile coastline supports diverse and dynamic fisheries. Each year, significant landings of approximately 65 species of fish and shellfish are made, about twice as many species as are landed along the Atlantic Coast between Maine and North Carolina. For their catch, California's commercial fishermen receive about $150 million annually. In addition, recreational anglers in the state spend hundreds of millions of dollars each year.

The past 20 years have seen rapid change in California's marine fisheries, and California Sea Grant has devoted a significant part of its research and extension resources to solving fisheries problems. The program area in fisheries has gone through three distinct phases, starting with basic studies in fisheries oceanography, then moving on to an emphasis on underutilized species, and most recently focusing effort on species and problems of prime management concern.

Pioneering work on age determination in sharks and other elasmobranchs filled in key information on age and growth and is used in managing shark fisheries worldwide.

Until 1974, fisheries research received relatively low funding within the program. Earlier studies had concentrated on basic fisheries processes in the California Current. In the tradition of past CalCOFI work, projects by John D. Isaacs of UCSD's Scripps Institution of Oceanography and Reuben Lasker and Alan Longhurst (of Scripps and what was then the Bureau of Commercial Fisheries) examined zooplankton, anchovies, and larval fish.

By 1974-75, fisheries projects were funded at a level similar to that of aquaculture. At least three factors led to this increase. First, advisory committees from the State Resources Agency and the seafood industry brought numerous fisheries problems to the attention of Sea Grant. Second, the expanding Sea Grant Extension Program rapidly became a conduit for identifying fisheries research needs and disseminating research results. And, most importantly, the impending federal Fishery Management and Conservation Act signalled opportunities for developing new fisheries and for diversifying from fully exploited fisheries like salmon.

Between 1974 and 1981, the fisheries research concentrated on underutilized or developing fisheries, including squid, sea urchins, sharks, and sablefish. The gradual phasing out of foreign fishing and the increasingly restrictive management of salmon motivated the fishing industry to expand and diversify.

In 1974, a major, four-year, multidisciplinary effort on market squid was initiated. Led by Tom Thompson of Moss Landing Marine Laboratories and Herbert Frey of the California Department of Fish and Game, this project provided basic information on population structure, reproduction, age determination, predation, and the influence of oceanographic variables on populations—information that was needed for development and management of the fishery.

At the same time, seafood technologist Paul Singh at UC Davis

developed a mechanical system for cleaning squid, which was licensed by the University to a Santa Cruz company for development. Growing interest in squid led to an expansion of the fishery to 26,000 tons in 1981, but before the influence of the machine could be realized, a dramatic El Niño event caused the fishery to collapse. The fishery has now recovered, however, and a modification of the squid machine is being used by industry today to produce skinned squid products.

Rapid development of the sea urchin fishery as a result of the work of Sus Kato of the National Marine Fisheries Service, plus a series of Sea Grant extension workshops on the export of urchins, led Paul Dayton and Mia Tegner of Scripps and Joseph Connell of UC Santa Barbara to study the sea urchin's role in nearshore ecology. With Sea Grant support, they discovered the importance of the canopy of spines provided by the adult animal as nursery habitat for juvenile urchins. Their work has been of critical importance in managing the urchin fishery, which has rapidly become California's largest and most valuable shellfish fishery (landings have in fact tripled since 1985).

Gregor Cailliet of Moss Landing Marine Laboratories worked on two rapidly developing fisheries: sablefish and shark. Cailliet investigated the biology and ecological role of sablefish in the deep waters of Monterey Bay. His use of traps as sampling gear was so successful that a large fishery immediately developed. Sablefish is now the most valuable groundfish species on the Pacific Coast, and Cailliet's work has proved useful in managing the fishery.

During the late 1970s, rapid expansion of shark fisheries raised concerns about the ability of the resource to sustain the harvest. Cailliet's pioneering work on age determination in sharks and other elasmobranchs filled in key information on age and growth and is used in managing shark fisheries worldwide. Most present shark management and research efforts at the state and local levels are based on Cailliet's work, and techniques he developed are being applied to billfish, sturgeon, and rockfish as well.

During the period of emphasis on underutilized species, California Sea Grant took a leadership role in funding socioeconomic studies in fisheries. Often classified as Marine Affairs, these projects investigated fisheries policy from economic, political science, historical, and anthropological perspectives. Michael Orbach of UC Santa Cruz completed a study of the economic failure and political success of Vietnamese immigrants in fisheries; it has formed the basis for a decade of important work with this group by the Sea Grant Extension Program and the Department of Fish and Game. Fishery policy studies by Biliana Cicin-Sain of UC Santa Barbara and others analyzed California's first experience with limited entry, the first years of the Pacific Fisheries Management Council, and conflicts relating to marine mammals and

fisheries. Dennis King of UC San Diego developed an input/output model for the state's fisheries that continues to be used widely by industry and government to predict the effects of changes in fishery policy on the economy.

In the area of seafood technology, research by several UC Davis scientists has focused on understanding biochemical processes and changes in fish products. Studies on discoloration, histamine reactions, and use of modified atmospheres have had the most significant impact on seafood science. William Brown's research on modified atmosphere storage continues to be used in developing and evaluating modified atmosphere packaging systems.

By the early 1980s, expansion of the fishing industry had slowed, and fishery management problems intensified. This marked the beginning of the third phase of California Sea Grant's fisheries research program. Because of the combination of increasingly diverse fishery research needs and level federal funding, California Sea Grant's program management decided to focus efforts on critical management questions and important species. Critical questions centered on population dynamics and the effects of environmental variables on fish and shellfish recruitment.

Recent investigations of the genetic structure of salmon and anchovy populations by Graham Gall and Dennis Hedgecock of UC Davis are proving particularly useful. Gall's work is being used by the Pacific Fisheries Management Council to refine zonal management to protect stressed salmon runs in certain river systems. At this time, a joint UC Davis/Department of Fish and Game laboratory for genetics studies is being developed.

Other important projects in population dynamics by Louis Botsford of UC Davis and David Hankin of Humboldt State University (on crab and salmon, respectively) are being utilized in managing these fisheries. Marc Mangel's work (UC Davis) on developing new methods for estimating stock abundance was immediately applied to egg and larval surveys of sardines to determine whether a commercial fishery could be allowed under state law, and it appears that the sardine fishery may once again become economically important to the state.

In 1986, California Sea Grant, in consultation with its industry and agency advisory committees, decided to focus a significant portion of the program's fisheries research on rockfish, a group of about 60 species that is the object of a large and growing commercial and recreational fishery. Projects on population dynamics, seafood technology, and age determination of rockfish are now under way.

Culturing Anadromous Fishes

Sturgeon aquaculture in California began in 1977 when a group of UC Davis researchers decided to develop a prototype sturgeon hatchery.

Anadromous fishes, such as salmon and sturgeon, leave the sea and ascend freshwater rivers in order to breed, a pattern of migration that makes them particularly vulnerable to human predation and to changes in their spawning habitat. During their migration from fresh water to saltwater and back again, these fishes necessarily undergo substantial changes in their body structures and physiologies, changes as yet only poorly understood.

One critical step in the salmon life cycle, for example, occurs when young fish at the freshwater parr stage metamorphose into seawater-adaptable smolts before beginning their journey to the sea. The process is known as "smoltification," and it is of vital concern to those involved in aquaculture and animal husbandry because under artificial conditions it too frequently fails.

In California, several salmonid species, but principally the coho salmon, have been selected for seapen culture as a way of enhancing their growth before they are released to the ocean. The fish are typically transferred from freshwater hatcheries to seapens when they weigh about fifteen grams and are presumed to have undergone smoltification. But if the young fish have not transformed fully into smolts, they suffer high mortality in the seapens: as many as 50 percent may die. In addition, there is considerable stunting among the survivors. Stunting may also be a major cause of mortality in the millions of fish annually released from hatcheries on the West Coast.

In 1974, using early successes in salmon seapen culture in the Pacific Northwest as their model, Christopher Dewees and Bruce Wyatt of California Sea Grant's Marine Extension Program began rearing coho and chinook in seapens off Tiburon in San Francisco Bay. Their experiments were funded by a local sportsmen's group and involved the cooperation of the National Marine Fisheries Service (NMFS) and the California Department of Fish and Game (CDF&G).

Early on, the high occurrence of stunts led them to seek the help of Richard Nishioka, a University of Tokyo Ph.D. and a research specialist in the laboratory of endocrinologist Howard Bern at the University of California, Berkeley. Initial examination of the stunts by Bern and Nishioka suggested that the problem might reflect endocrine dysfunction. So, with Sea Grant support, Bern and his associates began examining the complex endocrine system of coho.

When dwarfism is encountered, one typical assumption is that there must be a deficiency in growth hormone. Bern and his colleagues therefore conducted many hormonal studies on stunts, and though they determined that the stunts were generally deficient endocrinologically, the animals showed, surprisingly, a large excess of growth hormone.

Studies soon turned to thyroid hormone. At the time of smoltification, salmonids exhibit a surge of thyroid activity, and other

investigators had shown that a salmon's ability to grow in seawater is directly related to the proportion of the thyroxin surge it has completed before entering seawater. Though this surge appears to be an excellent indicator of biological readiness for entry into seawater, it varies in timing from year to year. Thus, to identify the timing of smoltification, individual salmon stocks had to be closely monitored for thyroid levels, a time-consuming and expensive process.

In collaboration with the CDF&G and colleagues in Washington State and in Japan, the Berkeley team was able to determine that the thyroxin surge coincides with the new moon following the vernal equinox, and that fish released from hatcheries at this time show up two or more years later in far greater numbers in the fishery, clearly suggesting greater survival. This ability to predict migratory readiness by the lunar calendar thus minimizes the need for blood sampling and complicated technology. As a consequence, several regions of the CDF&G now plan their salmon hatchery releases in consultation with Bern and his associates.

A recent discovery made at Bern's laboratory is the presence of thyroid hormone in salmon egg yolk—a finding that suggests that developing embryos, and later larvae, are provided with an environment enriched in maternal hormones even before their own endocrine systems develop. This is particularly interesting to the developmental biologist because it indicates that old ideas of early embryonic development as occurring essentially independent of hormones may have to be revised.

If thyroid hormones are transferred from the mother through the yolk, why not other hormones? Bern now suggests that we may need to look differently at developing organisms with yolky eggs. Such animals may have two overlapping endocrine sources at the yolk-sac stage: one from the yolk stores and the other from the developing animal's own endocrine system. Indeed, Bern's associate Chris Brown has shown that if female striped bass are injected with thyroid hormone before spawning, their eggs have significantly more thyroid hormone than usual, and their young show significantly higher survival, better and more regular development, and ultimately higher returns from culture ponds. So, in addition to revolutionizing basic concepts of the role of hormones in early development, this methodology for "yolk enrichment" with hormones promises to have a major impact on culture of various finfish species.

At the time Bern began his pioneering research, he and his associates felt isolated. Salmon are, however, of wide international interest and represent one of the most valuable fisheries in the Northern Hemisphere. Shortly after his group began their work, a West Coast "network" of salmon researchers emerged, involving primarily laboratories in Nanaimo, Seattle, Corvallis, and Arcata, in addition to

Berkeley. Annual workshops initiated by these laboratories attracted not only West Coast investigators but also scientists from around the country, plus representatives of government agencies and industry.

In 1981, California Sea Grant sponsored the first international symposium on salmon smoltification. Several Japanese investigators came to this meeting in La Jolla, and thus developed a Pacific Rim collaboration on salmonid biology that has proved mutually beneficial and that shows the possibility of being extended to New Zealand, China, and the USSR. Two additional international salmonid symposia were later held—in the United Kingdom and Norway—with extensive participation by the Berkeley team. A salmonid endocrinology is now a scientific reality.

The Japanese who are presently "networking" with the West Coast salmon biologists represent laboratories at the University of Tokyo, the National Institute of Basic Biology, Kitasato University, and the University of Hokkaido. In addition, a French endocrinologist from INRA (Rennes, France) maintains contact with West Coast laboratories and with Japan, and Scandinavian workers are associated with the laboratories at Nanaimo and Berkeley. With Sea Grant support, three top Japanese scientists and a French scientist have spent research periods in Berkeley. In return, and with Japanese and some Sea Grant funding, several Berkeley scientists have spent time in Japanese laboratories. The ease of contact among the several laboratories not only avoids wasteful duplication of effort but also contributes to the balance of trade in concepts and techniques. And support of this interchange of individuals has proved to be farsighted in eliminating the unhealthy aspects of competition.

As a result of such cooperation and collaboration, which has also involved CDF&G, the Berkeley researchers have begun to define the true role of the thyroid in salmon development and migration, to place in perspective the function of other hormones in salmon smoltification, and to elucidate the ionic and endocrinological basis of stunting in coho and Atlantic salmon.

The enhancement of smolt quality has obvious benefits to producers, and ultimately to consumers. Less obvious, but no less important, is the contribution made to the planning needs of a large number of agencies, councils, and regional and legislative bodies involved in resource mangement. For example, in Northern California, where the issue of water exports continues to be controversial, being able to predict release times well in advance may permit some reconciliation between those managing water resources and those managing the fishery.

Theodore Kerstetter at Humboldt State Universtiy has also looked at the phenomenon of stunting, but from the point of view of how and

why the saltwater environment ultimately leads to the condition. He has provided evidence that problems in the regulation of sodium and potassium ions within muscle and liver cells may be a factor in the failure of coho salmon to successfully adapt to seawater.

In addition to research on stunting, Sea Grant has supported work on imprinting, genetic structures of populations, and disease. At the University of California, Davis, Ron Hedrick has done important work on a devastating salmonid kidney disease called PKD (for proliferative kidney disease). Hedrick was able to determine that the amoeba-like protozoan that causes PKD is a member of the phylum Myxozoa and to describe previously unknown stages of the parasite's complex life cycle. He was also able to show that the infective stage (as yet unknown) is most prevalent in the summer months, and that fish that survive a first infection become strongly immune to the disease—findings that have affected the CDF&G trout restocking practices.

As a result of the knowledge of when to expect the first and most severe parasite infections, fish aquaculturists now manage the disease better, and mortality rates have dropped. Recently, his research has led to an effective therapeutic treatment for the disease—the first clearly successful medicinal approach to preventing a disease caused by a myxozoan parasite in salmonid fish. His workshops and publications have greatly increased consciousness of PKD and, therefore, its identification, and the Fish Pathology Laboratory at UC Davis has become internationally known as the leading laboratory for studying this kind of disease.

Like salmon, American sturgeon stocks have been heavily exploited. In the late 1880s, the United States was the world's second largest producer of caviar, but sturgeon were soon destroyed by overfishing and destruction of habitat. Today, serious and successful efforts are being made to domesticate sturgeon. The effort is spurred by the product's value: steaks can sell for $8 a pound and more.

Sturgeon aquaculture in California began in 1977 when a group of University of California, Davis, researchers, participating in a newly established aquaculture program, decided to develop a prototype sturgeon hatchery. The work was supported by California Sea Grant, the U.S. Fish and Wildlife Service, NMFS, and the U.S. Department of Agriculture and done in cooperation with the CDF&G and several private aquaculturists.

With fishermen's help, the Davis scientists captured ripe, wild sturgeon, which they were able to maintain successfully in captivity and to induce to spawn. During the following years, California Sea Grant supported a large interdisciplinary group of scientists,* who investigated the animal's reproduction, nutrition, physiology, and disease.

Their work was given an early and important head start by the

*Project leaders have been Joseph J. Cech, Jr., Wallis H. Clark, Jr., Serge I. Doroshov, and Graham A. E. Gall.

involvement of Serge Doroshov, a Soviet emigré and noted sturgeon specialist now at UC Davis. Aquaculturists became interested in the sturgeon, adopting techniques developed by the project.

California presently has 12 sturgeon hatcheries and 10 growers. Hatcheries routinely spawn domestically raised males, but they must still capture mature females (which in nature take 15 to 20 years to mature). Bringing cultured females to maturity is now a top priority of industry, and with Sea Grant support, Gary Moberg of the University of California, Davis, is working on this problem. Silas Hung of UC Davis is investigating nutrient requirements and optimal feeding rates.

Information on the hatchery technology developed through efforts by UC Davis researchers and cooperating commercial growers is now available in a manual prepared by Fred Conte, Extension Aquaculture Specialist, in collaboration with Doroshov and other Davis colleagues, and with support from the U.S. Fish and Wildlife Service.

California aquaculturists are now marketing fingerling sturgeon to other growers in the United States and Europe and to the aquarium trade, and the fish is being planted in lakes for recreational fishing. With the increase in 8- to 12-pound inventories, a test market for food-sized fish has been expanded into "white tablecloth" restaurants in Sacramento, San Francisco, and the East. There are many who believe that sturgeon farming will be among California's biggest aquaculture success stories.

Developing Centers for Crustacean Research

As was true for many of the state's prized fisheries, the fishery for the California spiny lobster suffered a dramatic decline during the years following World War II.

In response, four Sea Grant-funded lobster projects were initiated at San Diego State College (later, San Diego State University [SDSU]) as early as 1968. Three of these were associated with the California spiny lobster, *Panulirus interruptus*. They were designed not only to examine the declining fishery, but also to test the potential of culturing larval and juvenile stages for replenishment of natural populations, as well as to identify pathogenic microbes and chemical residues in natural populations. The fourth project dealt with the American lobster, *Homarus americanus*, an animal indigenous to the east coast of the United States. This study looked at the potential of introducing the American lobster to California's coastal waters.

Though the decline of spiny lobster populations has continued, and *H. americanus* is not an inhabitant of California's coastal waters, these early studies had a decided impact on future Sea Grant research.

H. americanus ultimately proved far too aggressive a companion for California crustaceans; however, it had many attributes that initially made it appear desirable for aquaculture. One of the more notable of these was its accelerated growth rate in warm water—for example, that produced by power plants. Funded jointly by California Sea Grant and San Diego Gas and Electric Company, SDSU scientists Richard Ford, Charles Krekorian, and Jon Van Olst spent several years developing the technology for warm-water culture of *Homarus*. These studies developed in unison with a program at UC Davis's Bodega Marine Laboratory (BML) directed by Robert Shleser.

The Bodega program had a strong disciplinary orientation and developed subgroups in algology, genetics, nutrition, pathology, and physiology. Over the years, smaller subprojects, supportive of major programs, were also funded. Examples include the work of Warren Johnston (UC Davis) on the economics of lobster culture, the studies by Prudence Talbot (UC Riverside) on various aspects of reproduction in lobsters, and the work by Harriette Schapiro and James Steenbergen (SDSU) on pathogens and immunization procedures for crustaceans.

As the above programs developed, new scientists were recruited with expertise in crustacean biology or training in disciplines pertinent to the questions being asked. Soon both San Diego State University and Bodega Marine Laboratory became recognized centers for crustacean research. The commercial sector became interested in lobster culture, and pilot operations were built and a healthy collaboration developed between commercial culturists and university investigators. Many of the obstacles facing the culturist (the development of artificial feeds, controlled breeding, and so on) were overcome, and it became apparent

Tests have shown that cryopreserved shrimp sperm are fully capable of "fathering" viable offspring—a breakthrough with enormous potential for aquaculturists.

that *Homarus* could be cultured.

By the late 1970s, phenomenal developments had been made with Sea Grant support. Douglas Conklin (BML) and his associates had developed an artificial diet, and least-cost formulations were being tried. The major diseases of lobsters had been described, and in most cases treatments were in hand. Dennis Hedgecock and Keith Nelson (BML) had developed techniques for controlling vitellogenesis and spawning by manipulating photoperiod and temperature. Controlled mating became a reality, and Talbot developed techniques for the artificial manipulation of gametes, such as artificial insemination.

Over this period, hatchery technology had been developed. Van Olst and Ford contributed significantly to work defining the conditions for optimal growth of the American lobster. But because of this species' inherent aggressiveness and tendency to cannibalism, individual lobsters had to be isolated, and this proved costly (domesticating the American lobster has been likened by one wag to housebreaking the rhinoceros). In the end, it was largely expense that limited the viability of commercial lobster culture. Nevertheless, the information acquired has had a significant impact on our understanding of crustacean biology.

During the late 1970s, UC scientists began working with marine shrimp of the penaeoid species. Aquaculture of marine shrimp had gained favor internationally, and aquaculturists were continually seeking advice from the "crustacean experts" in California's universities.

One of the primary problems this new industry was facing was a lack of seed stock: the shrimp's life cycle had not been closed and very little was understood about the animal's reproductive biology. At Bodega, Wallis Clark's laboratory initiated field studies designed to establish the reproductive season of a penaeoid shrimp found off the coast of California, *Sicyonia ingentis*. This species, also known as Pacific rock shrimp (or ridgeback prawn), supported a small fishery at Santa Barbara. It was soon determined that this animal was very hearty and thrived under laboratory conditions. In addition, it became obvious that its reproductive biology was very similar to that of other commercial penaeoids. As a result, *S. ingentis* has become a model system for reproductive studies in penaeoids. During the past years, basic understanding has been achieved of its reproductive cycle, the morphology of both sperm and eggs, the morphological changes that occur during gamete interaction, and what controls gamete activation.

In addition, Clark and his colleagues developed new techniques that allow them to manipulate many phases of the reproductive cycle of the Pacific rock shrimp. For instance, they can induce ovulation and spawning; they routinely achieve success rates for *in vitro* fertilization greater than 70%; and they have developed techniques for artificial insemination. Further, California Sea Grant has supported collaborative

studies between the laboratories of Clark and John Crowe (UC Davis) that have resulted in techniques for achieving cryopreservation of sperm—potentially one way of assuring hatchery managers of high-quality shrimp gametes throughout the year. Crowe has been able to show that the sugar trehalose is much more effective than are traditional cryoprotectants in preserving membrane structure during freezing and thawing. And tests by Clark and his associates have shown that these cryopreserved sperm are fully capable of "fathering" viable offspring—a breakthrough with enormous potential for aquaculturists, who have wanted a sperm bank so that they can better control quality and begin genetic manipulation for desirable traits. Clark and Crowe are now working with scientists at Texas A&M University and National Taiwan University to test the applicability of these results to penaeoid species in general, and to date the results are gratifying.

When the day of the lobster returns, California scientists will be ready to help. Ernest Chang continues to maintain the original lobster hatchery developed at the Bodega Marine Laboratory and uses lobsters as a model system for his Sea Grant studies on hormonal control of molting. His work on the molting hormone, ecdysone, is fundamental to our present knowledge of molting in the decapod crustaceans. Chang has isolated molt inhibiting hormone in lobsters, and he has been successful in sequencing the amino acids of this peptide. With these data, he has constructed a DNA probe that is being used to screen the genomic library of lobster DNA for the molt-inhibiting gene. It is hoped that the information gained will provide the necessary tools to produce an antigene that can then be used to promote growth.

Molluscan Aquaculture: Providing Gourmet Fare

This work has been used to improve the production of more than 15 different kinds of abalone and more than 20 different commercially valuable molluscs both in the United States and abroad.

Abalones are a prized catch in California, largely for their tasty flesh, but also for the pearly interior of their shells, said to vie in iridescence with a film of oil on water. From the inception of California Sea Grant, sharp declines in the landings of these shellfish have presented a major challenge. In the five years between 1968 and 1973, for example, annual landings decreased from four million pounds to about one-quarter that amount.

Sea Grant's first project in molluscan aquaculture did in fact focus on abalone. "Abalone Larval Ecology and Culture Methodology," funded in 1971 with David L. Leighton as project leader, initiated a line of research that spanned 15 years, involved scientists from several universities, and resulted in numerous scientific publications that had impact far beyond the state's abalone fishery.

Until Leighton's studies, only the larvae of the red abalone had been described. With Sea Grant support, Leighton successfully reared the larvae of five commercially important species of abalone and then went on to define the influence of temperature on larvae of three species, and of algal diets on the growth of post-larvae and juveniles.

The rationale for Leighton's work was really twofold: If abalone could be reared successfully under controlled conditions, it might be possible to operate hatcheries for restocking the depleted wild abalone fishery. And eventually it might be possible to establish a commercial abalone aquaculture program in California.

This pioneering work stimulated interest in abalone culture and highlighted problems with controlling spawning and with heavy mortality of newly metamorphosed juveniles. These problems became the focus of a series of projects led by Daniel E. Morse of UC Santa Barbara between 1975 and 1987.

The first problem to be attacked by Morse and his colleagues was that of inducing spawning. Building on earlier observations by Japanese workers that UV-irradiated seawater stimulated spawning, Morse and his associates showed that the underlying mechanism of this phenomenon was the enhancement by hydrogen peroxide (generated during UV-irradiation) of enzymatic synthesis of prostaglandin, a hormone that stimulates spawning. Morse then showed that hydrogen peroxide itself induced spawning, not only in abalone species but also in a number of other molluscs, suggesting that the prostaglandin mechanism for control of spawning is widespread in molluscs.

Having achieved a simple and inexpensive means for controlling spawning of abalone by hydrogen peroxide—a method that is now widely used in California and in other countries, including Japan—Morse and his colleagues turned their attention to the important question of what induces the free-swimming abalone larvae to undergo metamorphosis and settlement. This question continues to be an

important one, not only for molluscan aquaculture but also for the ecology and fisheries of molluscs, owing to the critical role of recruitment in the dynamics of natural populations.

Taking clues from preliminary studies showing that the larvae of red abalone are induced to settle by contact with specific crustose red algae, Morse and his associates identified chemical inducers of larval settlement and metamorphosis, particularly γ-aminobutyric acid (or GABA). With GABA as a convenient and inexpensive means for controlling the synchronous development of larvae, they also developed and demonstrated the sensitivity of an abalone developmental bioassay for environmental pollutants.

While implementation of the GABA technique for inducing metamorphosis has been slow in the United States because of the higher technological requirements, it is now being used on a routine basis by one commercial abalone company in California. Experiments with this method are in progress elsewhere, and it is being routinely used in New Zealand.

Further research led to refinements and extensions of these early findings on several fronts. Practical methods for inducing spawning and settlement in a variety of molluscs followed quickly. The ecological context of molluscan metamorphosis was elucidated, particularly the role of GABA-mimetic proteins on the surfaces of crustose red algae. Finally, a general biochemical mechanism controlling larval settlement and metamorphosis in marine invertebrates was postulated. It is clear that the field of molluscan development owes much to Morse's pioneering research and to the support of the California Sea Grant College Program. This work has been used to improve the production of more than 15 different kinds of abalone and more than 20 different commercially valuable molluscs both in the United States and abroad.*

Today, there are 4 commercial producers of abalone and 14 licensed companies in the earlier "research-and-development" phase. Many commercial operators rely on the research and extension activities of California Sea Grant to advance the state of their industry. For example, in September 1988, California Sea Grant sponsored a series of seminars on recent developments in abalone cultivation in Japan by Tetsuo Seki. Seki, director of the Oyster Research Institute in Japan, a private mariculture venture, met with California growers as well as university and agency staff to exchange information on both applied and basic research topics.

Beginning in 1977, Mia Tegner of UCSD's Scripps Institution of Oceanography and Joseph Connell of UC Santa Barbara, working in collaboration with the California Department of Fish and Game, initiated a series of projects designed, in part, to evaluate the scientific and economic potential for enhancing wild populations of abalone by

*In 1982, California Sea Grant hosted an international symposium sponsored by the Pacific Sea Grant College Program on "*Recent Innovations in the Cultivation of Pacific Molluscs*." The proceedings were published in 1984 by Elsevier.

outplanting of hatchery-reared juveniles, a method made feasible by the work of Leighton and Morse. Several small- and large-scale planting experiments with both red and green abalones yielded very low survival rates, however. And although much was learned concerning abalone ecology (one of the project's objectives), these studies failed to demonstrate that hatchery seed could be used to enhance wild populations. A number of factors were identified as the primary reasons for low seed survival in these studies, including dispersal of seed from areas of study and the fact that hatchery-reared seed have significantly different behavior patterns from wild animals of the same size classes. These behavior patterns (which relate to shelter selection) increase their susceptibility to predation.

In 1975, Sea Grant turned its attention to another mollusc that appeared to have potential as an aquaculture species, the purple-hinge rock scallop. In a series of four projects, Charles F. Phleger and David L. Leighton of San Diego State University developed successful methods for induced spawning and controlled fertilization, as well as hatchery rearing. They also conducted studies of the uptake by juvenile scallops of dissolved and particulate organic matter, tested long-term growth in a variety of holding systems and localities, evaluated a variety of collectors for catching wild spat, and conducted analyses of the scallop as human food. Today, there is at least one commercial operation in California that is collecting and growing out the wild seed.

Another major series of Sea Grant projects, led by Grover Stephens and his colleagues at UC Irvine, focused on the uptake by mussels, clams, and oysters of free amino acids dissolved in marine water. At least two "firsts" are justifiably claimed by these workers: (1) the first demonstration of net entry of amino acids into marine larvae from natural sources and in aquaculture systems and (2) the first bacteria-free culture of bivalve larvae in the United States—to conclusively exclude significant effects of contaminant microorganisms on the process of uptake.

The most striking result of this research is that a substantial portion of the total bivalve requirement for reduced carbon (up to 30 percent) may be obtained by uptake of amino acids from seawater. Further, these researchers were able to demonstrate the rapid and effective movement of free amino acids from the epidermis to deeper tissues of the animals. This research is presently being continued by Donal T. Manahan (a former associate of Stephens) at the University of Southern California, with support from the USC Sea Grant Institutional Program. The work could eventually have considerable impact on commercial bivalve culture, particularly as it merges with the development of micro-encapsulated artificial diets.

The most economically important mollusc cultured along the West

Coast of North America is the Pacific oyster, *Crassostrea gigas*, which was introduced from Japan at the beginning of the century. At present, *C. gigas* has an annual value of nearly $6 million in California alone.

The West Coast oyster industry has been greatly revitalized since 1980 by several developments that arose around the country: the introduction of methods for reliable hatchery production of eyed larvae (i.e., those competent to metamorphose), which can be shipped to growers for on-site setting; the introduction of methods for inducing triploidy (three sets of chromosomes rather than the normal two), a condition that renders the oyster sterile and therefore more marketable during the normal summer reproductive season; and the collapse of East Coast oyster fisheries, primarily because of disease.

This newly revitalized industry was not without problems, however, and California Sea Grant funded a project by Dennis Hedgecock at UC Davis to address heavy oyster mortality at settlement and metamorphosis. The project helped redirect research by faculty of the UC Davis Aquaculture and Fisheries Program toward industry problems. This led to the establishment of a molluscan culture facility at the Bodega Marine Laboratory and, under continued funding from California Sea Grant, to the development of facilities and culture methods allowing study of the genetic basis of early larval and juvenile mortality. Experimental groups of triploids and diploids have been deployed with the help of Fred Conte, UC Cooperative Extension Aquaculture Specialist, to plots on commercial oyster beds for evaluation of growth and survival.

Another study completed by Hedgecock yielded a surprising result. Electrophoretic examination and analysis of genetic variation in two commercial hatchery stocks and the wild population from which they had been isolated for three generations revealed that the commercial stocks, though comprising millions of oysters, were being propagated each generation by minuscule numbers of breeding individuals (average effective numbers of breeding individuals were between 9 and 41). Inbreeding and declines in performance would have occurred rapidly in these stocks had not corrective action been taken. The broader implication of this finding is that hatchery propagation of isolated populations is a necessary, but not a sufficient, condition for domestication and genetic improvement of aquaculture stocks.

In response to the desires of industry and university researchers to initiate cooperative research on oyster aquaculture, California Sea Grant sponsored a workshop in 1987 to identify appropriate goals. Titled "West Coast Mollusc Culture: A Present and Future Perspective," the conference and subsequent proceedings documented the enormous opportunities for West Coast growers and outlined the research that will be needed if these opportunities are to be realized. It is apparent that

modern biochemical and genetic techniques will increasingly be used to improve control over biological processes that limit the production of commercially valuable shellfish. It is also clear that future research will involve closer collaboration between the university and industry.

Investigating the Ocean's Potential to Yield New Products

Marine plants and animals are a genetically unique resource—very unlike land organisms—with vast potential for providing food resources, biological products, pharmaceuticals, agrichemicals, and industrial chemicals of novel types. This fact has provided a major rationale for California Sea Grant's strong investment in research oriented toward the potential of the oceans to yield new products.

The program's research efforts in new marine products began at the beginning of the 1970s. Early projects at UC Davis focused on food, seeking, for example, to find new anti-oxidants for the unsaturated fatty acids present in seafood and to determine why canned tuna tended to discolor.

Industry had been trying for years to find compounds with the properties of manoalide, but with little success.

At the same time, California Sea Grant began to invest in projects directly relevant to biomedical and agrichemical products research. Small programs at UC San Diego and UC Riverside initiated what is now a major focus of the program, the development of new pharmaceutical products from marine organisms.

Initial projects in this subject area probed for direction and applications in pharmaceutical research, and they achieved significant discoveries in basic science. In 1972, James J. Sims at UC Riverside made the surprising discovery that the metabolism of marine plants includes the incorporation of elements called halogens (chlorine, bromine, and iodine) from seawater into organic compounds. He and his colleagues showed that marine plants contain organohalogen compounds that are amazingly similar in structure to the halogenated pesticides, such as DDT and chlordane. This observation was expanded by D. John Faulkner of UCSD's Scripps Institution of Oceanography, who also developed a clear picture of this metabolic phenomenon in marine invertebrates. Later, the prevalence of these compounds in nature and the degree of interference they impart to the analysis of pesticide pollution were determined by a Scripps group headed by William Fenical. On the basis of these early studies, the phenomenon of marine halogenation was fully documented.

As a natural consequence of their discovery, Sea Grant researchers began to explore how these biodegradable marine compounds might be applied to agriculture. Investigations by Fenical and Phillip Crews of UC Santa Cruz explored their utilization as insect-control agents and herbicides. When naturally occurring compounds from red algae were found to possess insecticidal properties as powerful as those of DDT, several industries (FMC and Zoecon Corporations, in particular) utilized these findings to modify their scientific approach to the development of synthetic agrichemical products. Recent research by Isao Kubo at UC Berkeley has returned to the potential of marine plants to yield biodegradable agrichemicals of new classes. Kubo is also investigating novel growth promoters isolated from red seaweeds found off the

California coast.

In 1975, researchers under the direction of Neylan Vedros of UC Berkeley discovered that some red seaweeds from California's coastal waters contain compounds with powerful antiviral properties. They showed that extracts of the seaweed were capable of controlling Herpes simplex viruses, and they developed full University patent protection for their discovery. In 1978, a neuronal blocking substance was discovered by researchers at Stanford University's Hopkins Marine Laboratory. Later, researchers within a UC Santa Barbara group headed by Robert Jacobs discovered a powerful new toxin, lophotoxin, which had been isolated by Fenical from a California soft coral.

These fundamental findings provided the basis for more expanded studies of the biomedical potential of marine organisms—a focus that was to create significant growth within the Marine Natural Products subject area.

Late in 1977, a unique project was established within California Sea Grant: the Marine Pharmacology Program. This program was the first effort organized within the United States to discover and develop new pharmaceuticals from marine sources. The program was unique in that it established a collaborative effort between natural products chemists from UC San Diego (Fenical and Faulkner) and UC Santa Cruz (Crews) and pharmacologists from the developing program at UC Santa Barbara headed by Jacobs. This collaborative multicampus event was unprecedented within the structure of Sea Grant programs, and the internal cooperation established has set the tone for the subsequent 10 years of productive research. In addition, California Sea Grant's Marine Pharmacology Program provided testing facilities for other UC researchers and cooperated with Sea Grant scientists from many other universities.

The Marine Pharmacology Program soon gained considerable momentum and began to focus on several new areas of pharmacological development, with an emphasis on inflammatory diseases and cancer. By 1985, the group had a backlog of discoveries. Over 600 purified compounds had been isolated from various marine plants and animals, and there were significant commercial findings worthy of prompt patenting. In the meantime, the University of California Patent Office was responding to the intense need to expand patent acquisitions within the context of biotechnology. In five short years, the UC Patent Office grew from two to over thirty employees, and patenting of new Sea Grant discoveries began.

Early in the evolution of this research effort, it became clear that an effective program would require the participation of industry. Sea Grant researchers introduced pharmaceutical companies to their work, both to solicit financial help and to request assistance in advanced testing and

development. Most importantly, participating industries provided the sophistication of a business perspective and the rigors of clinical testing, both of which subsequently guided the direction of research in this subject area. Sea Grant researchers have continued to interact closely with industry to make, patent, and develop numerous discoveries that would not otherwise have been pursued.

In 1985, the Jacobs and Faulkner groups collaborated in the discovery of an unprecedented new class of anti-inflammatory agents, based upon the structure of manoalide, a compound isolated from a tropical sponge. Jacobs and his associates recognized manoalide as a powerful inhibitor of inflammation and its resultant pain and recognized the potential of the compound to compete for sales of anti-inflammatory drugs in a $200 million annual market. Most importantly, manoalide was understood to act by the direct inhibition of phospholipase A2, a mechanism unique among all known anti-inflammatory agents.

Industry had been trying for years to find compounds with the properties of manoalide, but with little success. The Allergan Company (a division of Smith Kline and French Laboratories) became involved immediately, and it has subsequently participated as the sole developer of the manoalide class of anti-inflammatory agents. The compound has been the subject of four University patents and has become a major focus of Allergan Company. The company presently holds an exclusive option license for the development and marketing of the compound or its derivatives, and it projects clinical trials within the next few months. In addition, a number of companies, including Eli Lilly, Hoffman La Roche, Dupont, Allergan, and Wyeth, have programs centered on developing manoalide-like drugs—that is, drugs that are similar in their action. The discovery of this compound and elucidation of its mechanism of action are probably the most important contributions Sea Grant has made to the biomedical field.

More recently, Crews and his colleagues have collaborated with the Syntex Corporation in the development of two new classes of antifungal and anthelminthic drugs. His efforts have resulted in patent applications by the University for the compounds jasplakinolide and bengazoles A and B, novel cyclic compounds that represent major advances in these therapeutic areas.

Another example of successful discovery and patenting is the pseudopterosins, a class of powerful anti-inflammatory and analgesic agents recently discovered by the Fenical and Jacobs groups. The pseudopterosins were isolated from a Caribbean soft coral, and they are, like manoalide, structurally and pharmacologically unique. Since they act via a new mechanism of action, the pseudopterosins, too, represent novel contributions to the study of inflammatory disease. The University has processed two patents covering this class of compounds, and there

are several industries, including Bristol Myers, involved in assessing their commercial development. Recently, a project by K.-P. Wong at California State University, Fresno, has investigated substances from the skeleton of sharks and rays that may combat tumor growth. And a research group at UC Santa Barbara is investigating compounds from red seaweeds and marine bacteria that mimic the action of GABA, a neurotransmitter in the human brain and spinal cord. The work on GABA has been directed by Daniel Morse, who heads the new Marine Biotechnology Center at the Santa Barbara campus.

For the past two decades the National Sea Grant College Program (and specifically California Sea Grant) has been the single major funding source for marine pharmaceutical research and development. Perhaps the major success of the effort to date has been that it has allowed marine science to become linked with the pharmaceutical industry.

Looking ahead, it is clear that there will be an increasing need to develop new drugs, particularly for AIDS and other viral diseases and, of course, in cancer chemotherapy. In each of these areas we can be sure that new directions will be sought based upon the underexplored resources found in the sea.

Forecasting to the future, new marine resources will be earmarked for study. Marine microorganisms, in particular, will become a major focus as scientists and biomedical researchers seek to realize the untapped potential of this massive group of largely unknown organisms. Molecular techniques will become essential in marine biomedical research, and genetic methods will become a standardized tool within new marine product research and development. California Sea Grant's focus on biomedically relevant research will clearly be enhanced in the future as new scientific methods and capabilities are discovered.

Ocean Engineering Under California Sea Grant

In order to assess the accomplishments of California Sea Grant in ocean engineering over the last 20 years, it is instructive to recall a bit of the political, economic, and scientific context in which the developments took place.

Twenty years ago, in the 1960s, this nation was fighting a very unpopular war; it was also landing men on the moon. The country's energy consumption was growing exponentially, and as a consequence of the depletion of cheap land-based oil fields (chiefly in the Southwest), we were relying more and more on foreign crude oil.

In engineering, the emphasis was on building more and larger oil tankers, even though the technology of offshore oil drilling was progressing at a steady clip, principally in the Gulf of Mexico. Though never completed, the "Mohole" project, designed to drill through the Earth's crust, spawned the design of innovative structures for operating in the ocean and provided concepts that had a profound effect on the embryonic offshore oil industry. It was during this time too that oil was discovered in the North Sea, but the environment was thought too harsh to permit large-scale production.

This growing cadre of former Sea Grant trainees is making a significant impact on ocean engineering and on the health of this nation's offshore industry.

It was also at this time that the term "ocean engineering" was coined, principally because none of the older, traditional disciplines of naval architecture, petroleum engineering, or oceanography seemed quite to fit.

Simultaneous with this activity, there were tentative forays into the oceans. "Hydrospace" was billed as the equivalent of outer space, but such achievements as deep submersibles and advances in diving never captured the imagination of the general public as did the space program.

Much was made of the discovery of mineral-rich deposits on the ocean floor (the so-called manganese nodules). But interest waned once people discovered that the best deposits were 3,000 meters below the ocean's surface, that there was a limited market for these minerals, and that the job of recovering and processing them was extremely difficult and expensive.

Several very deep-diving research submersibles were built, but many did not have a defined scientific mission—nor were the costs of supporting these vehicles realized until it was too late.

Nonetheless, Cousteau became a household name, and sports activities like skin diving became popular. The sixties were a time when people were also becoming more concerned about the environment.

It is against this backdrop that ocean engineering emerged as a profession and the National Sea Grant Program came into being.

In California, one early question was which university in the state should be designated *the* Sea Grant College. UCSD's Scripps Institution of Oceanography was, of course, one leading contender, but significant independent (and for the most part uncoordinated) activities were taking

place at other campuses of the UC system, in the State University system, and at private universities as well.

In response to this competition, the statewide University of California administration set up an ad hoc panel to develop a comprehensive plan. It was only natural that Robert Wiegel, a UC Berkeley professor with a long history of involvement in coastal engineering, be selected a member of this panel, which was chaired by Benny Schaeffer of Scripps. From the first, this panel recognized the strong interdisciplinary character of research in the oceans and recommended that the statewide program involve all of the campuses.

In the beginning, the Ocean Engineering subject area of Sea Grant was a very modest part of the overall program, centered primarily in La Jolla. In reality, the money available for engineering projects was small, and the concept of matching grants was foreign to the academic community interested in these problems. Also, other funding sources were available for traditional engineering disciplines, and many investigators sought these funds instead.

The site review was another aspect of the early Sea Grant Program that adversely impacted the subject area, for the site review team frequently seemed indisposed to supporting engineering projects. Nonetheless, the 1971 program saw the initiation of eight different, and in retrospect seminal, ocean engineering projects, including submarine soil mechanics (by Iraj Noorany of San Diego State University), aspects of offshore platform design (two separate projects by J. Randolph Paulling and William Webster of UC Berkeley), underwater exploration devices (Glen Wade of UC Santa Barbara), and underwater vehicles (Victor Anderson of Scripps). In addition, there were several projects headed by IMR director John Isaacs and his Scripps colleagues. All in all, it was a banner year; but things were to change rapidly.

In those early days, the site review team was an extremely powerful influence in the proposal selection process. One frequent member of the team at that time had a particularly strong influence on the future development of the research subject area. As a partner in a private research company, he was adamant that Sea Grant sponsor no research that could be performed adequately by private consulting companies. Further, he and his colleagues on the site review team felt (and not without just cause) that engineering that would benefit the offshore oil industry should be paid for in full by the industry itself, particularly since Sea Grant had so little funding.

Unfortunately, the oil companies were loathe to sponsor research in the universities because they insisted on proprietary rights, which at that time conflicted with university policy.

The result was that during the 1970s precious little engineering research aimed at the principal offshore industry—offshore oil

production—was conducted at any university.

However, the Arab oil crisis of 1973 caused a revolution as dramatic in impact as any war. Suddenly energy cost ten times what it had only a few years before, and it was only natural to look to ocean reserves to determine if they could be tapped. Drilling for oil in the North Sea became extremely attractive, as did drilling in even harsher climates, like the Arctic. Tanker construction stopped abruptly (in fact, only a handful of tankers have been built since then). Further, the hunt was on for alternative energy resources. In addition to the land-based solar and wind-collecting schemes, a plethora of devices for extracting energy from the ocean were proposed for study. These included OTEC (Ocean Thermal Energy Conversion), wave power schemes, harnessing of major ocean currents, and even tapping of salinity gradients.

It is impossible to discuss this topic without also mentioning John D. Isaacs, a giant of a man, both physically and mentally, and with charisma and charm to match. Isaacs, whose career encompassed many different disciplines from oceanography to marine biosystems, was from the start a key player in California Sea Grant's ocean engineering program. The oil crisis focused Isaacs on energy problems, and in his own careful and methodical way, he cataloged and analyzed each of the potential retrieval schemes. Isaacs actually constructed and demonstrated the feasibility of some of the devices that resulted from this study, one of which will be described in more detail in a later report.

Beginning in the late 1970s, many of Sea Grant's "growing pains" in ocean engineering were resolved. University-wide participation in this component increased, and in the last few years this subject area has included projects from all of the campuses, as well as other universities and colleges.

Most of the proscriptions against performing research related to the exploration and extraction of offshore oil disappeared as the urgency of national competitiveness grew. At the same time, participation by the oil companies themselves in the form of matching grants increased.

Many of the projects undertaken in recent years actually follow the lead of those started in 1971, falling into three fairly coherent themes:

(1) Work systems in the ocean (from sonar and other exploration devices to bottom-crawling unmanned vehicles).

(2) The safety of engineering systems in the ocean environment (aimed at issues relating to the safety of docks, offshore oil-storage structures, oil-drilling platforms and ships, and the materials used to construct them).

(3) The properties and behavior of subsea soils (including their ability to support work vehicles, pipelines, and platforms).

Finally, no overview would be complete without mention of two

very important spin-offs that are easily overlooked in a quick review of the program.

The first is the yearly Sea Grant subject-area meetings, involving California's ocean engineering academic community. Subject area meetings have allowed researchers and their students from several institutions to establish important contacts with one another. It still appears difficult to mount research projects that span campus boundaries, but the communication provided by the meetings has led to a synergy among researchers in broad areas.

The other important product has been graduate students in engineering, a critical national need. Through the years, Sea Grant projects in ocean engineering have supported many students through their master's or Ph.D. degree programs. For many if not most of these students, the Sea Grant-sponsored research in which they were involved was a principal motivating factor in their graduate education and their subsequent career paths. This growing cadre of former Sea Grant trainees is making a significant impact on ocean engineering and on the health of this nation's offshore industry. In the end, they represent every bit as important a product of the program as does the research.

"Clearly Sea Grant can escape from the dominance of specified and perpetually frozen approaches to perpetually frozen and oftimes meaningless objectives, a condition that besets most large national programs. It can profit from the flexibility of small approaches, taking a long shot and discerning the unexpected or even, perhaps, discovering the inconceivable. It can profit immensely from the synergism and intercommunication of new mixes of intellectualities and proclivities: intelligent and informed laypersons, broad scientists, specialists (excepting, of course, dingy-spirited ones), engineers, technicians, industrialists, and politicians. It can avoid being entrained in common misconceptions of the sea. It is and can remain a refreshing, revivifying, and evolving force working around and over and perhaps even disinterring the frozen mastodons now buried in the terminal moraines of large programs."

John D. Isaacs, 1978

Improving Technology for Working in the Oceans

From the inception of California Sea Grant to the present, ocean engineering has been an important component of the program, designed to improve our basic technology for working in the oceans. Over the years the emphasis has been on several fronts: curriculum development, graduate thesis support, instrument development, theoretical studies, and laboratory and ocean experiments.

The first Sea Grant award in California was for a curriculum development proposal that related directly to ocean engineering. This project, headed by Victor Anderson of Scripps Institution of Oceanography, sought to develop an interdepartmental, interdisciplinary graduate program at UC San Diego in Applied Ocean Science. In addition to the graduate department of Scripps, it involved the Department of Applied Mechanics and Engineering Science and the Department of Applied Physics and Information Science.

Two developments actually stimulated this interdepartmental effort. The first was the early establishment by Sea Grant of traineeships for graduate student support. And the second was the provision of special funds by the Regents of the University of California to support four faculty billets at Scripps in support of the proposed Sea Grant project.

Over the four-year period (1968-72) that Sea Grant supported the initiation of this program, over 100 doctoral students enrolled. New courses were organized in acoustics, inshore processes, turbulent mixing and transport, and methods of geophysical measurement. An existing course on inshore processes was expanded. At the same time, students were required to take courses in a variety of disciplines (marine biology, geology, etc.) and to attend weekly seminars in Applied Ocean Science designed to expose them to a wide spectrum of practical aspects of scientific work in the sea.

Today, Applied Ocean Science continues to be an interdepartmental Ph.D. program concerned with purposeful and useful intervention in the sea. It combines the resources of three departments to produce oceanographers who are knowledgeable about modern engineering and instrumentation, as well as marine-oriented engineering scientists who are familiar with the oceans. Since physical, chemical, geological, and biological aspects of the oceans and all forms of engineering may be involved, the curriculum provides maximal flexibility in meeting the needs of individual students. About 30 students are presently enrolled in the program, with six or so doctorates being completed per year.

With regard to Ocean Engineering efforts *per se*, it is impossible to describe California Sea Grant's early work without invoking the memory of John D. Isaacs, professor of oceanography at Scripps and director of the systemwide Institute of Marine Resources, who provided

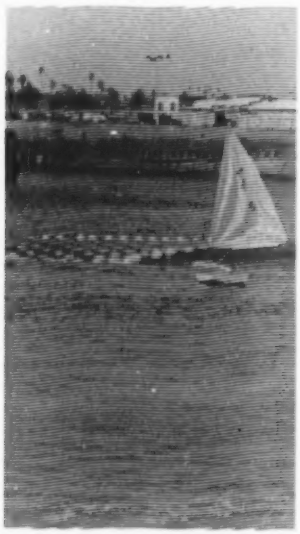
The dormant capability of RUM III came to life in a NOAA project to study the impact on seabed ecology of mining for manganese nodules.

large numbers of innovative concepts in ocean technology.

Several of Isaacs' projects dealt with ways of handling the tremendous store of power carried in ocean waves. One project, an effort to derive useful power from wave motion, was a wave-power machine—"machine" because it moved, albeit in a very simple manner. The concept reflects the fertile mind of Isaacs, who recognized that a ship commonly has an order of magnitude greater power in its up and down motions than in its propulsion. This notion led him to develop a new system for generating energy. A buoy, floating on the surface of the ocean was coupled to a long pipe that extended deep enough to be out of the orbital motion of the surface waves. As the buoy rose and fell with the surface waves, the pressure at the bottom of the pipe varied with the depth of the end of the pipe. By placing a foot valve (check valve) at the bottom, this oscillating pressure was rectified to provide an average pressure in the pipe that exceeded that of the average depth. As a consequence, water in a reservoir in the buoy up at the surface was pressurized above sea-level pressure and could drive a turbine to generate power. One of Isaac's students built a scale-model wave-power buoy that shot a continuous water jet several feet into the air as a visual demonstration of the concept. It was moored for several months off the beach at Scripps.

Another Isaacs project, undertaken in 1972 with trainee Richard J. Seymour (now a research engineer at Scripps), was development of a tethered floating breakwater. It formed part of a project that sought to develop inexpensive and portable methods of building breakwaters on the open coast and in the open ocean.

The essence of this concept was that a buoy, tethered in shallow water, could be tuned in its natural frequency response to surface waves in such a manner that it would absorb and scatter a significant amount of energy from the wave. An array of such tethered buoys could scatter enough energy to serve as a protective barrier for a pier or mooring subjected to wave action.



With the cooperation of the U.S. Navy and the California Department of Navigation and Ocean Development, a scale-model breakwater array was installed in San Diego Bay as a demonstration project. It proved to be very effective in dissipating both wind waves and ship wakes. Plans were made to develop a full-scale installation to protect the entrance to Avalon harbor on Catalina, but the installation was never completed because of jurisdictional disagreements among the agencies involved.

The dynamic breakwater project illustrates a policy that Sea Grant had to adopt early in its history. Because most engineering efforts rapidly become expensive when they enter the prototype construction stage, the program now generally sponsors engineering projects only

through the exploratory stage. Further, projects that center on student thesis research are encouraged, including those that utilize or provide data to larger engineering projects.

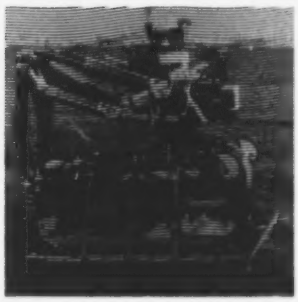
One example of the impact of the Sea Grant program on ocean technology is in the field of remote manipulation systems on the deep seafloor. Anderson initiated his first Sea Grant project in this field back in 1969. At that time, under Navy sponsorship, a remotely operated seafloor crawler equipped with TV cameras and a manipulator arm was being developed. The vehicle, RUM II (RUM for Remote Underwater Manipulator), was a redesign of an earlier version built in 1959. As RUM II became involved in operations in the ocean off Southern California, a Sea Grant project was initiated to study the effectiveness of remote seafloor work.

Several operations were covered under this project—recovery of some engineering test moorings in the Santa Barbara Channel for the Navy Civil Engineering Lab, soil strength measurements in the San Diego Trough, and biological studies (Project Quagmire), also in the San Diego Trough.

The most extensive of these, Project Quagmire, was a 30-day operation in which biologists from a number of institutions intensively observed and conducted experiments on the seafloor at a depth of 1,000 meters using RUM II as an extension of their hands and eyes. The participants in Quagmire were enthusiastic over the new capabilities that the unmanned vehicle placed at their disposal. New firsts in understanding the ecology of the deep seafloor were attributed to the performance of RUM II in the project.

A few years later, some of the biologists of the Quagmire project became participants in the Sandia Laboratory Seabed disposal project, and their enthusiasm for the sort of capabilities they had experienced with RUM II stimulated a design study for a new and improved vehicle that would work on the abyssal plain sediments of interest for seabed disposal of nuclear wastes. The design developed new concepts for an unmanned seafloor work vehicle, RUM III, that would perform as a tethered, remote seafloor crawler on the very soft sediments of the abyssal plains. Although enthusiasm was high, constraints on equipment funding precluded the fabrication of the vehicle within the context of the Seabed disposal project.

In 1981 the opportunity to develop the new RUM III occurred in the form of an equipment grant to Scripps by the Fleischman Foundation. Approval was obtained for $300,000 from the grant to be used as matching funds for a Sea Grant project. In the ensuing three years, the vehicle concept took shape in a Sea Grant project titled "Design of a Seafloor Work Station." It culminated in a successful sea test of the basic vehicle chassis, manipulator boom, and the cable power



and control system.

After a hiatus, the dormant capability of RUM III came to life in January 1987 in a NOAA project to study the impact on seabed ecology of resedimentation associated with mining of manganese nodules. (A marine biologist who had been a graduate student on Project Quagmire insisted that RUM III was the only vehicle that could conduct the required experimentation *in situ* on the deep seafloor.) Under this NOAA sponsorship RUM III was fleshed out with a manipulator, tracks, and other instrumentation to an operational vehicle. A four-week test trip in August 1987 in the Catalina Basin vindicated the marine biologist's confidence. In his words, "We collected more samples in this trip than we could have gotten in two years with *Alvin*. The box cores were the highest quality, undisturbed samples we have ever obtained."

The system is now being configured to operate from a conventional oceanographic ship, the *New Horizon*, and is scheduled in the NOAA program for a major expedition to a manganese nodule area south of Hawaii to conduct the *in situ* resedimentation experiments. Interest is developing in the use of RUM III in other resource assessment projects, particularly in the investigation of spreading center resources.

The seeds of seafloor work technology, sown many years ago by Sea Grant, are bearing fruit today.

Enhancing the Safety of Offshore Structures

Some of the very first Sea Grant projects at UC Santa Barbara grew out of the infamous blowout at Union Oil's Platform A in the Santa Barbara Channel on January 28, 1969. These early projects were to point the way to what would become an intensive area of effort by California Sea Grant researchers aimed at improving the safety of offshore structures and activities.

One of the first of these projects (1969-71) was an investigation of the seismicity and earthquake hazards of the Santa Barbara Channel by Arthur Sylvester. Sylvester's work became the basis for the seismic portion of the verification requirements for platforms off Southern California. It was later extended by William Prothero.

In 1975, the "Ocean Engineering" program area was renamed "Energy Resources R&D." An assortment of projects were initially included under this heading, including wave climate modification and the biological effects of waste-heat effluents from coastal power plants. Over time, however, increasing emphasis was placed on hazards involved in offshore oil development—though the subject area was once again renamed "Ocean Engineering," and was again more broadly envisioned as encompassing the wider scope of ocean technology.

The development of petroleum resources off California presented Sea Grant with a unique challenge: to focus on safety, risk assessment, and reliability of operations in the marine and offshore environment. This opportunity has been significantly augmented by exploration and drilling activities in Alaska and the Arctic since much of the engineering there has been carried out by California engineers. Similar involvement has now extended to the North Sea, the Mideast, and Australia.

In order to better meet the challenge of offshore oil development, projects supported by California Sea Grant have addressed the risks imposed on oil-production platforms, submarine pipelines, and other coastal structures by a spectrum of environmental hazards, including earthquakes, seafloor instability, waves, icebergs, and sea ice.

Sea Grant researchers have also considered the risks imposed on such structures by internal structural defects, such as corrosion, fatigue, and damage (for example, from ship collision).

These studies have focused on safety, where "safety" includes safety of life, safety against pollution, and safety against loss of resources.

It is difficult to separate considerations of safety from the methodology that must be incorporated in proper engineering design. So, where current practice has appeared inadequate or yet to be developed, Sea Grant-sponsored projects have specifically addressed methodology. For example, a project headed by Ben Gerwick, Jr., of UC Berkeley, has addressed the methodology needed for construction in the Beaufort Sea off Alaska, where dramatic environmental conditions have necessitated

Publications resulting from Sea Grant research form the basis for important sections in the standards, especially in providing safety against earthquakes and sea ice.

emphasis on safety through all stages of construction and operation.

Other research has dealt with breakwaters and offshore and coastal fills, seeking to find appropriate procedures to prevent the migration of fines under wave action, with consequent slumping and instability.

With regard to the reliability of offshore structures, special attention is called to a pioneering series of studies conducted between 1980 and 1983 by UC Berkeley researchers Robert Wiegel, Joseph Penzien, William Webster, and Ben Gerwick, Jr., on the effects of earthquake loading on large offshore oil structures and bulk terminals in deep water. In this research, analytical models were developed and computations made of the complex interactions between structures, water, and soils under seismic excitation.

Present research on the safety of existing steel platforms for continued service, headed by Gerwick and Robert Bea, has as its objective the eventual development of an expert system to facilitate evaluation of the more than 4,000 steel offshore platforms in U.S. waters, many of which are more than 25 years old and thus predate present knowledge of environmental forces. This project has received additional support from the U.S. Minerals Management Service and the U.S. Coast Guard as well as from industry. Preliminary progress indicates that the system may have application to a wide range of existing structures and facilities for which the consequences of failure are unacceptably high.

Sea Grant-sponsored research has played a leading role in the overall accumulation of improved knowledge and practice. The resulting publications have been referenced and form the basis for important sections in the standards, especially in providing safety against earthquakes and sea ice.

Although specific projects were initiated on an individual basis, taken together they form a coherent body of advanced knowledge whose importance continues to grow. The "coherence" has been achieved by the informed initiative of the individual investigators and by the careful sequence of Sea Grant review processes.

Research projects were conceived within the framework of global and national engineering efforts to improve the safety of facilities and operations in an obviously hostile environment. Project leaders have thus benefited from work being carried out by many others, among which are the U.S. Coast Guard, Minerals Management Service, the American Bureau of Shipping, the oil industry, and regulatory and standards bodies of Norway, the United Kingdom, and Canada.

A continuing program of this type necessarily must respond to critical safety needs as they become apparent. Should more funding become available, significant contributions could be made by Sea Grant researchers looking more deeply into future engineering needs related to deep-water structures and operations.

The California Sea Grant Extension Program

Part of Sea Grant's mission is to move the results of the research it sponsors out of academia and into the hands of people who use or manage California's coastal and marine resources. Conversely, the program seeks to make university scientists aware of the information needs of a variety of "client" groups: these can be fishermen, seafood consumers, aquaculturists, lawmakers, government agency personnel, or members of the public.

Sea Grant's primary arm for achieving this two-way linking function is its Sea Grant Extension Program. Administratively housed within the University of California Cooperative Extension, the program utilizes both field advisors and technical specialists to provide information and advice to a wide variety of groups.

Advisors and specialists necessarily became involved in a wide variety of projects. In this report, however, we have focused on one major area of involvement for each.

Sea Grant's Marine Extension Program is coordinated by Ronald O. Skoog, Natural Resources and Wildlife Specialist, Sea Grant Extension Program, Cooperative Extension, University of California, Davis, CA 95616.

Christopher M. Dewees
Marine Fisheries Specialist

Dewees conducted the only study of what really happens when an ITQ system is implemented.

Marine Fisheries Specialist Chris Dewees was the first full-time staff member of the Sea Grant Extension Program, joining it in 1972 directly from a Peace Corps assignment as a visiting professor of fisheries at the Catholic University of Valparaiso, Chile. In addition to commercial fishing experience, he brings to the extension program a master's degree in fisheries biology from Humboldt State University and a doctorate in human ecology from UC Davis.

Dewees has injected a strong social science influence into the extension effort. This has led to changes in the program's methods, consideration of new fishery management alternatives by industry and agencies, and development efforts in recreational fisheries. "I feel strongly that we shouldn't expend much effort developing ways to catch more fish, especially when most resources are fully exploited," says Dewees. "In the end it just raises everyone's costs to catch the same amount of fish." Instead, Dewees thinks that efforts should be made to find ways to lower fishermen's costs, raise their revenues, develop underutilized resources, and wisely manage the state's fisheries.

His 1984 study of technical innovation by Pacific Coast fishermen provided marine advisors with detailed information on fishermen's decision-making behavior, allowing the advisors to design more effective extension strategies. As a result, program methods have largely switched to highly visible applied and demonstration research, close

cooperation with industry opinion leaders, and publication in trade journals. These methods are particularly effective in projects involving on-board handling of fish, energy efficiency, and underutilized fisheries. "We learned that listening to fishermen is critical. Understanding their perceptions of new techniques or equipment is the key to designing strategies to encourage adoption," says Dewees.

During a 1987 sabbatical leave, Dewees conducted an in-depth socioeconomic study of the early effects of New Zealand's revolutionary individual transferable quota (ITQ) system on fishermen and fishing companies. It is the only study of what really happens when an ITQ system is implemented. ITQs are one of the primary methods now being considered for managing fisheries, and Dewees's documentation of the benefits and problems of ITQ implementation is being used by industry and government leaders throughout the United States, Canada, and Australia.

Dewees is also applying social science expertise to California's recreational fishing industry. The charterboat industry has been slowly declining for 20 years, and new ideas are needed to revitalize it. Dewees conducted a survey of charterboat anglers' information sources, perceptions of charterboat fishing, and suggestions for improvements. Based on the survey results, two marketing experiments are underway with industry cooperation. One involves the use of refrigeration to increase angler acceptance of underutilized species, such as mackerel, and the other targets corporations as a potential charterboat market. He believes that these applications of research-based information will help revitalize this industry.

Dewees feels that the strength of the Sea Grant Extension Program is its multidisciplinary approach. "We need to combine the social sciences with biology, seafood technology, and engineering to attack California's fisheries problems," says Dewees. "No matter how theoretically sound a new concept or technology is, people will only utilize it if they perceive that it is appropriate and advantageous for them. It is our job to select and mold research-based knowledge into a form that is useful to those involved in fisheries."

Address: Sea Grant Extension Program, U.C. Cooperative Extension, University of California, Davis, CA 95616. (916) 752-1497.

Robert J. Price
Seafood Technology Specialist

Ice has traditionally been used to preserve dressed Pacific salmon on commercial trollers, but for a variety of reasons—increasing cost, limited availability, and the time and effort required to ice fish at sea—the use of chilled-water systems in place of ice became popular on West Coast trollers in the early 1980s. There was a problem, however. The

quality of fish held in these liquid systems was often low. And it was not clear whether the loss of quality resulted from improper mixtures of saltwater and fresh water in the chilled systems, from improper handling of the fish, from temperature abuse, from prolonged fishing trips—or all of the above.

Quality is the particular concern of Seafood Technology Specialist Robert J. Price, who holds a Ph.D. in food science from Oregon State University and works closely with academics and industry personnel to increase seafood quality control at every step from fisherman to retailer.

To try to improve the quality of Pacific salmon reaching consumers, Price initiated a study on the relative effectiveness of ice and three different refrigerated liquids: seawater, fresh water, or a mixture of the two. His co-investigators included Marine Fisheries Specialist Christopher Dewees, advisors Edward Melvin and Bruce Wyatt, and staff research associates Michelle Bronstein and Elizabeth Strange. Cooperating with this team were personnel from the National Marine Fisheries Service, the Oregon Sea Grant Marine Advisory Service, Producer's Seafood, the Pacific Coast Federation of Fishermen's Associations, plus the *F/V Anna Louise* and *F/V Peggy L.*

This project has increased industry awareness of salmon quality and handling techniques.

The study indicated that all three chilled-water systems retarded bacterial growth slightly, thereby offering a potential advantage to ice. Of the liquid systems, the mixture of seawater and fresh water resulted in less salt uptake by the fish tissue than did seawater alone. This is important because salt can accelerate oxidation and rancidity in salmon during subsequent frozen storage. As compared with fresh water, the mixture resulted in less weight gain by the salmon. To provide acceptable quality throughout the typical seafood distribution chain, Price's team also provided guidelines on handling and on how long fish stored on vessels under different systems should be held.

Recommendations from the study were presented at 13 workshops in California and Oregon, at the 1983 Fish Expo, several commercial fishermen's association meetings, and the annual meeting of the Pacific Fisheries Technologists. The Sea Grant Extension Program also published a pamphlet on the subject in addition to two articles for *National Fisherman* and one for *Marine Fisheries Review*. Dewees later examined the adoption of Sea Grant's recommendations by the salmon fleet in his dissertation.

"As a result of this project," Price says, "salmon trollers have adopted the handling techniques and recommendations for chilled-water systems developed by California Sea Grant, and their associations have recommended that salmon fishing trips be limited to about five days to ensure that the quality of fish landed is high. The project has definitely improved industry awareness of salmon quality and handling techniques."

For this and other work on seafood quality, Price was recently named a fellow of the Institute of Food Technologists.

Address: Food Science and Technology, U.C. Cooperative Extension, University of California, Davis, California 95616. (916) 752-2193.

James B. Waldvogel
Area Marine Advisor
Del Norte and Curry Counties

The concept of statewide public conferences on salmonid enhancement, which began with California Sea Grant's marine advisors, has now spread throughout the Northwest.

It would be hard to overestimate the contribution of volunteers in bringing back the salmonid fishery resources of the state. For over 25 years, volunteer groups throughout Northern California have been rearing young salmon and steelhead for stream replenishment and working to improve stream habitat. These volunteers started many of their projects with enthusiastic public support and raised funds through their own efforts. In recent years, the California legislature has provided millions of dollars through enhancement funds and resource bonds, thereby making possible projects that in earlier years would not have been feasible.

Early in the 1980s, Sea Grant marine advisors in Northern California realized that many of the volunteers had only limited knowledge of fisheries and that lines of communication among the groups were weak. Three advisors (Christopher Toole, Bruce Wyatt, and James Waldvogel) came up with the notion that an annual statewide conference would make an excellent vehicle for training volunteer and nonprofit groups and putting them in touch with one another.

In January 1983, the advisors coordinated the First Annual Salmon and Steelhead Restoration Conference, in Eureka, California, cosponsored by the Department of Fish and Game and a number of enhancement groups. The conference was a huge success, drawing over 150 people from all over Northern California. The advisors developed sessions to train volunteers in subjects like salmonid genetics, capturing broodstock, building weirs, and providing spawning gravel. The conference quickly became a major annual event. The advisors organized the meeting again in 1984 and 1985 and then passed the torch to the California Salmon and Steelhead Restoration Federation, which assumed primary sponsorship in 1986.

Jim Waldvogel, a Sea Grant advisor whose arena of activity covers both Del Norte County in California and Curry County in Oregon, saw the potential of these conferences for other areas. "Working towards the enhancement of fishery resources brings a community together," observes Waldvogel, who has a master's degree in fisheries from Humboldt State University. "We suddenly see cooperation among people who have more often than not been at odds with each other—

sports fishermen, loggers, commercial fishermen, land developers, and public agencies. It's very rewarding to see these groups working together to improve their way of life and the environment."

Oregon had established an enhancement program called STEP (Salmon Trout Enhancement Program) in 1980, but the volunteer groups in that state were out of touch with each other. "I realized from the California experience," Waldvogel said, "that the frustrations of many of the volunteers would be reduced and the skills of individuals enhanced if that state were to initiate a statewide conference similar to California's." He convinced the necessary agencies that the 250 groups in Oregon could be unified by an annual conference, and in 1985 the first statewide meeting was held at Newport, sponsored by Sea Grant and the Oregon Department of Fish and Wildlife. That annual conference now draws over 400 volunteers each year.

The concept of statewide public conferences on salmonid enhancement, which began with California Sea Grant's marine advisors, has now spread throughout the Northwest. In 1988, Waldvogel attended Washington's first statewide conference of salmonid enhancement groups, and he also was the featured speaker at the first province-wide conference on enhancement in British Columbia—both the direct result of the successful California experience.

Address: Sea Grant Extension Program, U.C. Cooperative Extension, Del Norte County Courthouse Annex, 981 H Street, Crescent City, CA 95531. (707) 464-4711.

Christopher Toole
Area Marine Advisor
Humboldt and Mendocino Counties

Because most commercial fisheries are harvesting fish stocks at or near their maximum sustainable levels, improvement of the profitability of fishing can best be achieved through some combination of increasing the value of the product and decreasing the costs associated with catching it.

Towards this latter goal, Chris Toole has been working on a project to improve fuel efficiency in the California fishing fleet. He has been assisted by other marine advisors in the Sea Grant Extension Program and graduate students from UC Berkeley's Naval Architecture Department.

Toole and his colleagues initially prepared pamphlets for commercial fishermen describing ways to conserve energy and distributed them at workshops held along the coast. He also wrote the initial proposal for a state program that is now providing $900,000 in low-interest loans to California fishermen who are interested in adopting

fuel-saving technologies. He and advisors Ed Melvin and Jim Waldvogel and specialist Chris Dewees have served on an advisory committee to the California Energy Extension Service, which administers the loan program. "A 1988 evaluation of the first 17 loan program participants conservatively estimated their collective savings at $98,000 for the life of the technology," he says.

Information from field tests is loaded into a statewide database that will be used to show overall effects of fuel-saving technologies on several fishing vessels.

Inappropriate propellors are one cause of inefficient fuel use, so Toole and his associates have used a computer program to determine if a fisherman's propellor is properly matched to his boat. As a service to fishermen, the advisors have also performed field tests to generate power curves based on fuel consumption and speed at different rpm's. These tests are valuable in evaluating the performance of a boat before and after modifications are made and for determining the most fuel-efficient running speeds. Information from the tests is loaded into a statewide database that will be used to show overall effects of fuel-saving improvements.

To provide highly visible examples of some of these changes and to gather detailed measurements from which to document resulting energy savings, Toole and others have demonstrated a variety of fuel-saving technologies on several vessels.

In a project that used grant funds from the California Energy Extension Service, the hulls of two vessels were coated with self-polishing, antifouling paints. Fuel savings from using these paints were then compared with savings from using regular "sloughing" antifouling paints.

Several demonstrations have been performed on trawlers since these boats burn between 20,000 and 50,000 gallons of fuel each year. New hydrodynamically designed trawl doors were tested against the standard V-doors used in the fleet, and it was found that fuel use during towing was reduced an average of 6 percent with the new technology. And a new shrimp trawl with large mesh in the forward part of the net was shown to require less fuel for towing while catching identical volumes of shrimp as did a standard net.

The success of the demonstration projects and educational program has attracted the interest of several other states, and this past summer Toole travelled to Alaska as a guest of energy officials and extension agents there who are trying to develop a similar program.

Toole, who holds a master's in biology from Humboldt State University, has also been involved in developing test fisheries for several species, as well as developing a computerized system for helping oyster growers track water quality, and determining optimum conditions for holding Dungeness crabs in containers to extend the marketing period.

Address: Sea Grant Extension Program, U.C. Cooperative Extension, Foot of Commercial Street, Eureka, CA 95501. (707) 443-8369.

Bruce B. Wyatt
Area Marine Advisor
Marin and Sonoma Counties

Last summer Raley's Supermarket chain was one of a growing number of food stores in California to feature "organically grown" table grapes. What consumers probably didn't realize was that the grapes were grown with the aid of liquid fish, fast becoming known both for stimulating plant growth (without manufactured growth stimulators) and for reducing the need for pesticides.

Consumer demand for "chemical free" products may provide an answer to the vexing problem of how to dispose of mountains of seafood waste.

Marine advisor Bruce Wyatt believes that consumer demand for "chemical free" products may provide an answer to the vexing problem of how to dispose of mountains of seafood waste—and to good purpose. Only 25 percent of sole is used when fillets are cut, for example; the rest of the fish—skin, viscera, bone—simply becomes waste.

Wyatt has surveyed farmers' use of liquid and emulsified fish in various parts of the country and investigated the effectiveness of using a variety of marine waste products as fertilizers or additives to livestock feed. In New York, he reports as one example, a wine producer is spraying liquid fish on grape foliage to promote growth; in Nebraska, an organic farmer is using liquid fish on 700 acres of alfalfa, corn, and soy beans; and in Massachusetts, scientists are investigating liquid fish as a fertilizer supplement for cranberries. A survey by the Alternate Farming Program at UC Davis showed that one-fifth of 120 local organic food producers used fish waste at some stage in the growing processes.

"It makes all kinds of sense to use fish waste as fertilizer and as supplements to feed of different kinds," says Wyatt, who has a master's degree in fisheries from Oregon State University. "Not only is seafood waste rich in minerals and trace elements, but it can cost a fortune to dispose of. It also has a variety of other uses—from coloring salmon flesh to controlling nematodes."

California Sea Grant's role in helping industry develop new technology for waste utilization has been significant. With the assistance of Sea Grant's advisors and specialists, one industry has developed a liquid fish fertilizer that is being marketed to home gardeners and plant owners and a fish compost product that is a mixture of fish waste and sawdust.

In the past three years, Wyatt has been focusing on sea urchin waste. Liquid sea urchin, developed from the animal's viscera, shows promise as a foliage spray and a fertilizer for home and garden plants.

The animal's shell and remaining viscera are being studied for use on forage crops for livestock, such as clover. Wyatt was recently able to get enthusiastic cooperation from an urchin processor, a dairy rancher in Tomales Bay, and the California Water Quality Control Board to set up a demonstration project to study optimal application rates of urchin waste on pasture. He has also completed a compost demonstration project using cow manure and urchin shells and viscera and plans to initiate a project to determine at what stage of chemical degradation the protein products are most effective.

In 1988, Wyatt was one of those honored by UC Cooperative Extension with a distinguished service award for demonstrating the value of the "concurrent marketing concept" in promoting both local seafood and local wine.

Address: Sea Grant Extension Program, U.C. Cooperative Extension, 2604 Ventura Avenue, Room 100-P, Santa Rosa, CA 95401. (707) 527-2621.

Connie Ryan
Area Marine Advisor
San Francisco Bay Counties

Ryan led a multi-agency effort to produce a Vietnamese-language video on the subjects of safety and survival at sea.

Marine advisor Connie Ryan has been a leader in designing and implementing educational programs to meet the needs of the Vietnamese-speaking fishing community in California. During the last decade, hundreds of immigrants from Vietnam entered California fisheries. Most of them spoke limited English, and thus had difficulty getting vital information on practices and regulations in their new homeland.

An educational needs assessment conducted by Ryan and advisor Ed Melvin identified safety at sea as the area in which Vietnamese-speaking fishermen had the greatest need. Their lack of safety equipment and their inability to communicate with the Coast Guard in English were resulting in great loss of lives and vessels. In one three-year period, over 10 percent of the commercial fishing vessels owned by Vietnamese immigrants in central California were lost in boating accidents, and eight Vietnamese-speaking fishermen died.

To make information available to these commercial fishermen, advisors Ryan and Melvin worked with various government agencies and fishing associations between 1983 and 1986 to develop and conduct innovative workshops on safety.

In 1987, Ryan led a multiagency effort to produce a Vietnamese-language video on the subject. The 60-minute video, titled "Safety and Survival at Sea: A Training Film for Vietnamese Fishermen," was filmed with the close cooperation of the Vietnamese fishing community

and the Coast Guard. It provides viewers with the most basic tools for achieving safety at sea. The video illustrates required safety equipment, procedures for calling the Coast Guard in an emergency, and how to give a boat's position in English. The video has been used by individual fishermen and fishing associations in California, on the Gulf Coast of the United States, and in Canada.

"The safety classes and video have had a significant impact on the safety practices and economic well-being of the Vietnamese-speaking fishing community in California," says Ryan. And Coast Guard radio operators are now better able to understand emergency calls from the immigrant fishermen.

Ryan, who holds a master's degree in marine biology from San Francisco State University, is also concerned with issues of water quality and has served on the Cooperative Extension Water Policy Task Force.

Address: Sea Grant Extension Program, U.C. Cooperative Extension, P.O. Box 34066, San Francisco, CA 94134. (415) 586-4115.

Edward Melvin
Area Marine Advisor
Monterey and Santa Cruz Counties

Ed Melvin's work in restoring coastal wetlands for the National Estuarine Research Reserve at Elkhorn Slough provides a good example of how Sea Grant's extension programs grow out of local needs. When Melvin, who has a master's in fisheries biology from Humboldt State University, took on the role of area marine advisor in Monterey and Santa Cruz counties, he did not expect to get involved in designing wetlands. But he has now been Sea Grant representative to the advisory committee for the research reserve for over eight years, and he finds satisfaction in the contribution he has made both to restoring the reserve and shaping its activities.

Elkhorn Slough, in northern Monterey County, is the second largest remaining coastal wetland in California, a state that has lost over 90 percent of its original wetlands. Designation of the 2,500-acre area as California's first estuarine research reserve in 1979 established it as a living laboratory for research and education.

Soon after the establishment of the reserve, a Research Reserve Advisory Committee was named, which included community leaders and agency and university representatives, as well as the NOAA Office of Coastal Resource Management and the California Department of Fish and Game, which has primary responsibility for management of the reserve. A number of questions regarding wetland restoration demanded the committee's attention, including kinds of habitats needed, possible saltwater contamination of the aquifer, flooding liability, use of heavy

As a result of these efforts, over 500 acres of coastal wetlands were added to those existing in Elkhorn Slough, creating critically needed habitat for a host of plants and animals.

equipment on a soft substrate, and costs. Two large areas of diked pastureland were obvious candidates for re-establishing tidal flows. However, as Melvin recalls, "it became clear that wetland restoration technology was at best 'emerging' and that if these areas were to be restored we were going to have to do it ourselves."

The committee first undertook restoration of the larger of the two areas. "In retrospect," says Melvin, "our initial lack of consensus on the relative importance of different objectives led to some frustrations. I was particularly concerned that we consider the aesthetics of the area and its research potential in addition to its value for wildlife."

Despite some difficulties, 200 acres of pastureland and another 200 acres of adjoining but badly degraded wetland were eventually returned to tidal flows. Now, five years later, the area is home to over 30 species of fish and over 100 species of resident and migratory birds, plus a host of saltmarsh plants.

Having learned from this initial experience, Melvin and the coordinator of the reserve program, Mark Silberstein, then spearheaded a review of the second parcel. This project presented new challenges because unrestricted tidal flow would have flooded a section of county road and adjoining pasturelands. With the input of Sea Grant scientists from San Diego State University and UC Santa Barbara, Melvin and Silberstein worked with the Department of Fish and Game to come up with a restoration concept that included a tide-control structure and limited channeling. With mitigation funds from California Department of Transportation, they also worked with a local researcher to improve the interpretive and research potential of a small area near the Visitor Center.

As a result of these efforts, over 500 acres of coastal wetlands were added to those existing in Elkhorn Slough, creating critically needed habitat for a host of plants and animals. The reserve is also successfully filling its role as a research site: several NOAA projects have focused on colonization of the newly created marshes, and there are presently ten research projects underway.

During his involvement with the project, Melvin has chaired both the advisory committee and the education subcommittee, and he continues to serve on the research subcommittee. The reserve now has over 80 volunteers, many of whom are involved in public education. More than 300 teachers and 10,000 students have participated in education programs there, and 30,000 to 40,000 persons visit the reserve each year.

Address: Sea Grant Extension Program, U.C. Cooperative Extension, P.O. Box 480, Moss Landing, CA 95039. (408) 633-2092.

John B. Richards
Area Marine Advisor
Ventura, Santa Barbara, and San Luis Obispo Counties

During a meeting with Santa Barbara Channel trawl fishermen in 1976, marine advisor John Richards was told about a costly problem of gear loss that fishermen believed was caused by oil pipelines and uncharted submerged well heads in areas that had traditionally been productive trawl grounds. Torn nets were common, he learned, and these could cost a fisherman one or more days of lost fishing time. If both net and trawl doors were lost, replacement costs could mount to $5,000—a significant amount for a small fishing operation.

With the assistance of the director of the office of the U.S. Geological Survey in Ventura, Richards established a system for identifying incidents of lost or damaged equipment and developed ways of mitigating losses. In one case, four nets and several trawl doors worth over $10,000 were retrieved, and fishermen were reimbursed without costly litigation.

This situation could have been avoided, he realized, had there been a mechanism by which the oil and fishing industries and the regulatory agencies communicated regularly during the planning phase for oil exploration. So, with the aim of reducing potential conflicts and assisting agencies in obtaining needed information, Richards initiated a long-term project. "I hoped that ultimately the oil/fisheries project would encourage an atmosphere of compromise and cooperation," he says.

The project was initially only a small part of his south-central California extension effort, but as offshore leasing accelerated in the early 1980s, more of the fishing fleets were affected and conflicts intensified.

The advisor's office soon became a clearinghouse for information, and Richards facilitated numerous meetings, providing a neutral forum for discussion.

He coordinated a cooperative research project on the problem of anchor scars left during the laying of pipelines, which prevented shrimp trawlers from working productive grounds. And he set up a prototype system to provide fishermen with advanced notice of seismic surveys.

Though these actions helped, conflicts continued to grow, and Richards sought funding through the federal Coastal Energy Impact Program to develop a pilot project to distribute information in a more timely and efficient manner. In 1983, he was awarded a $22,000 grant to initiate a monthly newsletter, the *Oil and Gas Project Newsletter for Fishermen and Offshore Operators*. The newsletter, presently coedited by staff assistant Carolyn Culver, has proved to be an effective means of

communication, and funding for it continues to be provided by the oil industry, the fishing industry, county agencies, and the Sea Grant Extension Program.

Richards, who has a master's in fisheries biology from Oregon State University, also introduced oil and fisheries representatives to professional mediators and assisted the mediators in establishing a Joint Oil and Fishing Industry Committee for negotiating specific problems and a Liaison Office to deal with day-to-day operations.

Offshore energy development continues to be a contentious issue along the whole West Coast, and Richards has held training workshops for regional Sea Grant advisors and specialists.

Offshore energy development continues to be a contentious issue along the whole West Coast, and Richards has held training workshops for regional Sea Grant advisors and specialists. He has also provided information on oil/fisheries conflict resolution to the Canadian Government, and he has made presentations before the Pacific Fisheries Legislative Task Force and the Washington State Joint Select Committee on Marine and Ocean Resources. Recently, he coordinated education sessions on offshore oil development for members of Washington Sea Grant's Ocean Resources Assessment Program.

Richards has also been active in shellfish aquaculture development, fisheries development, and in promoting cooperative life-history studies of species that are the focus of expanding fisheries, including the ridgeback prawn, angel shark, and sheep crab.

Address: Sea Grant Extension Program, U.C. Cooperative Extension, 377 Storke Road, Goleta, CA 93117-2989. (805) 681-5630.

Leigh Johnson
Area Marine Advisor
San Diego, Los Angeles, and Orange Counties

San Diego is home port to a fleet of 50 to 60 commercial passenger-carrying fishing vessels, which depend heavily on a lucrative summer and fall fishery for tunas and yellowtail. Most anglers used to exchange their fresh catch for canned fish, but by 1985 this practice had become costly and unreliable, for all but one Southern California tuna cannery had closed.

The canning process tends to mask changes in fish texture and flavor; thus, as more anglers began to take their fish home fresh, demand for better handling practices increased.

Although many captains of these sportfishing vessels believed that client satisfaction with their catch was linked to repeat business, they also knew that it would increase costs to improve on-board quality. They wanted to know under what conditions it would be cost-effective to improve handling practices on one-day fishing trips. They also wanted to know whether sports fishermen would actually use literature on at-home quality control and cooking methods and whether such information

would increase consumer satisfaction with catch.

To address these questions, marine advisor Leigh Johnson, in cooperation with Seafood Technology Specialist Robert Price and other Sea Grant extension staff, conducted on-board research during 1987 and 1988. They monitored core body temperatures of fish under traditional (in damp gunny sack on deck) and experimental (in barrel of slush ice) conditions for five species of tunas, the related bonito, and yellowtail. In addition, 236 anglers were given baseline interviews plus literature on how to handle, store, and cook fish properly. Later, 97 anglers responded to a follow-up survey on the impact of the literature.

The interviews disclosed that most of these sportfishermen are after more than the thrill: they view their catch as food. Most anglers take most or all of their catch home, and eat it, though only a slight majority bring the fish home in an insulated cooler with ice. Most of those who don't keep much of their catch cite poor quality as the reason. A follow-up survey showed that after anglers had received educational literature, 10 percent kept more of their catch, 18 percent improved handling practices, and 16 percent ate more of their fish.

After anglers had received educational literature, 10 percent kept more of their catch, 18 percent improved handling practices, and 16 percent ate more of their fish.

Research conducted by the Sea Grant extension staff aboard the vessels found that the most important factors influencing the cooling rate of fish were body weight and ambient temperature. The traditional method for controlling quality on one-day trips—evaporative cooling in damp gunny sacks—proved ineffective in reducing fish temperatures. On the basis of their work, the extension staff advised vessel captains that all fish be protected from high temperatures. Further, because small fish respond quickly to ambient temperature, it is especially important to chill them on warm days. Large fish respond slowly to temperature changes, so it may not be cost-effective to chill them on cool days. Finally, "shelf life" is especially important to anglers with large amounts of fish, so chilling is advisable for trips when many fish are caught.

Sportfishing captains have found this information useful and volunteered to cooperate in developing a "fish chilling decision manual" for the commercial passenger-carrying fleet. They are also cooperating in research on effective packaging materials for storing frozen tuna at home. A final element of this project is a demonstration to introduce anglers to vacuum packaging and freezing for home storage of sportfish.

With marine advisor Connie Ryan, Johnson has also completed a survey of 200 coastal waterfront managers in California. The survey, which among other things identifies the technical and managerial information managers feel they most need, will form the basis for an extension program of research and education.

Address: Sea Grant Extension Program, U.C. Cooperative Extension, 5555 Overland Avenue, Building 4, San Diego, CA 92123.
(619) 694-2845.

Education—A Commitment to the Future

Since its inception, California Sea Grant has supported over 600 graduate student trainees in fields as diverse as oceanography, ecology, engineering, law, geology, and food science.

The commitment of California Sea Grant to education and training in the marine sciences is evident in the projects it supports for students at all levels, as well as for teachers and for the public.

Trainees

Since its inception, the California Sea Grant College Program has supported over 600 graduate student trainees in fields as diverse as oceanography, ecology, engineering, law, geology, and food science. Recent surveys of former trainees show that 57% have obtained doctorates and 42% master's degrees. Over 42% have entered private industry, 20% have become college or university faculty, and 24% are working in colleges and universities in non-faculty positions. Nearly 14% are working in government at the local, state, or federal level.

John D. Isaacs Scholarship

California Sea Grant awards a college scholarship each year to a high school senior who shows particular aptitude in marine science. Winners have been:

1981. Amy Kimball, Point Loma High School, San Diego. Kimball is presently a PhD candidate in biology at The Johns Hopkins University.

1982. John Wikert, Santa Maria High School. Wikert is completing a master's degree in fisheries management at Frostburg State University, Maryland.

1984. Mwenda Kudumu, Gompers Secondary School, San Diego. Kudumu completed an undergraduate degree in biology at Stanford and is working as a biologist for the National Marine Fisheries Service. She plans to enroll in a PhD program.

1985. Michael Topolovac, Torrey Pines High School, Del Mar. Topolovac is working toward a degree in product design at Stanford.

1986. Steen Trump, McKinleyville High School. Trump is a biology and environmental studies major at UC Santa Cruz.

1987. James Randerson, Pt. Loma High School, San Diego. Randerson is completing his sophomore year at Stanford University.

1988. Russell Scott Shapiro, University City High School, San Diego. Shapiro began studies at Humboldt State University. His teacher, William Reed, won the first Isaacs Teacher Recognition Award.

National Fellowship Program

The John A. Knauss Sea Grant Fellowship Program, sponsored by the National Sea Grant College Program, matches graduate students who have demonstrated interest both in ocean policy and marine science with government "hosts" in Washington, D.C. California Sea Grant's National Fellows have been:

1983. Robert Deibel, M.S., Humboldt State University. Presently a fisheries biologist with the Federal Energy Regulatory Commission in

Washington, D.C., Deibel was a Sea Grant Fellow with the House Merchant Marine and Fisheries Committee.

1984. Victoria Fabry, PhD, UC Santa Barbara. Fabry, who served as a Sea Grant Fellow with the Senate Committee on Commerce, Science and Transportation and in the office of Congresswoman Barbara Boxer, is a postdoctoral investigator in chemical oceanography at Woods Hole.

1985. Justin Lancaster, J.D., Vermont Law School; M.S. and PhD candidate, Scripps Institution of Oceanography. Lancaster was a Fellow with the Senate Committee on Environment and Public Works and is completing his PhD at Scripps on biospheric feedbacks to the greenhouse effect.

1986. Keith Criddle, PhD candidate, UC Davis. Criddle is presently an industry economist with the National Marine Fisheries Service in Seattle, where he served as a Sea Grant Fellow.

1986. Dan Smith, PhD, UC Santa Barbara. Smith was a Sea Grant Fellow with the House Committee on Science and Technology and is presently head limnologist with Lycott Environmental Research in Southbridge, Massachusetts.

1987. Pablo Arenas, PhD, University of Washington. Arenas was assigned as a Fellow to NOAA's Office of Climate and Atmospheric Research. He is presently a research scientist with the Inter-American Tropical Tuna Commission in La Jolla, California.

1988. Alan Dietz, PhD candidate, UC Irvine. Dietz was selected to work as a Fellow on the Senate Committee on Environment and Public Works as part of the staff of Senator Max Baucus. In this position, he drafted legislation for regulating the release of genetically engineered organisms.

State Fellowship Program

In 1987, California Sea Grant initiated a California State Fellowship Program. State Fellows have been:

1988. Craig Denisoff, Master's candidate, San Francisco State University. Denisoff was assigned to the California Legislature's Joint Committee on Fisheries and Aquaculture and is presently working as a consultant to the committee.

1989. Robert Wilder, PhD candidate, UC Santa Barbara. Wilder is presently a Fellow with the staff of Assemblyman Dan Hauser, vice-chair of the Joint Committee on Fisheries and Aquaculture and chairman of the Pacific Fisheries Legislative Task Force.

In addition, California Sea Grant has supported programs of public and teacher education at five university-based institutions: Humboldt State University, the Moss Landing Marine Laboratories, UC Santa Cruz, UC Santa Barbara, and the Aquarium-Museum at UCSD's Scripps Institution of Oceanography.

Isaacs Scholar Michael Topolovac

Committees

Institute of Marine Resources Advisory Council

Richard E. Attiyeh
Dean
Graduate Studies and Research
University of California, San Diego

John P. Craven
Director
The Law of the Sea Institute
University of Hawaii, Honolulu

Murray Dailey
Director
Southern California Ocean Studies Consortium
California State University, Long Beach

Thomas B. Day
President
San Diego State University

Frank D. Drake
Dean, Division of Natural Sciences
University of California, Santa Cruz

C. M. (Tod) Ghio
Ghio Seafood Products
San Diego, California

W. F. (Zeke) Grader, Jr.
General Manager
Pacific Coast Federation of Fishermen's Associations
Sausalito, California

Theodore L. Hullar
Chancellor
University of California, Davis

Robert W. Morse
North Falmouth, Massachusetts

Ernest L. (Roy) Perry
Retired Executive Director
Port of Los Angeles

David S. Potter
Santa Barbara, California

Nathan Sonenshein
RADM, USN (Retired)

Roger Thomas
President
Golden Gate Fishermen's Association
Sausalito, California

Gordon K. Van Vleck
Secretary for Resources
Resources Agency of California
Sacramento, California

James H. Zumberge
President
University of Southern California
Los Angeles

Resources Agency Sea Grant Advisory Panel

Gordon K. Van Vleck, Chairman
Secretary of Resources
Resources Agency
State of California
Sacramento, California

Peter Bontadelli
Director
Department of Fish and Game
Sacramento, California

Peter Douglas
Executive Director
California Coastal Commission
San Francisco, California

William H. Ivers
Director
Department of Boating and Waterways
Sacramento, California

Donald L. Keach
Director
Hancock Institute for Marine Studies
University of Southern California
Los Angeles, California

Senator Barry Keene
State Capitol
Sacramento, California

Assemblywoman Sunny Mojonnier
State Capitol
Sacramento, California

Gerald A. Pollock
Hazard Evaluation Section
Department of Health Services
Sacramento, California

Richard Ridenhour
Dean, College of Natural Resources
Humboldt State University
Arcata, California

Robert E. Ross
Executive Director
California Fisheries and Seafood Institute
Sacramento, California

Theodore C. Smith
Technical Planning Officer
Division of Mines and Geology
Sacramento, California

Fred N. Spiess
Institute of Marine Resources
University of California
La Jolla, California

F. Robert Studdert
Johnson Oyster Company
San Rafael, California

Wilbur M. Thompson
State Lands Commission
Long Beach, California

Dan Walsh
State Water Resources Control Board
Sacramento, California

Elmer P. Wheaton
Portola Valley, California

California Sea Grant Committee

James J. Sullivan, Chairman
Director
California Sea Grant College Program
University of California
La Jolla, California

Victor C. Anderson
Deputy Director
Marine Physical Laboratory
Scripps Institution of Oceanography
University of California, San Diego

John H. Crowe
Professor of Zoology
University of California, Davis

William T. Doyle
Director
Institute of Marine Sciences
University of California, Santa Cruz

Cadet H. Hand
Director Emeritus
Bodega Marine Laboratory
University of California, Davis

Robert W. Holmes
Professor of Biological Sciences
University of California, Santa Barbara

Theodore H. Kerstetter
Professor of Zoology
Humboldt State University
Arcata, California

Edward B. Lyke
Professor of Biological Sciences
California State University, Hayward

Alec D. MacCall
Acting Director
Tiburon Fisheries Laboratory
National Marine Fisheries Service
Tiburon, California

Richard J. Seymour
Research Engineer
Institute of Marine Resources
University of California
La Jolla, California

Joy B. Zedler
Professor of Biology
San Diego State University

Director
USC Sea Grant Program
Institute for Marine and Coastal Studies
University of Southern California
Los Angeles, California

Subject Area Coordinators

Fisheries and Aquaculture

Wallis H. Clark, Jr.
Bodega Marine Laboratory
University of California, Davis
Bodega Bay, California

Coastal Resources

Reinhard E. Flick
Center for Coastal Studies
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, California

Marine Affairs

Harry N. Scheiber
Boalt Hall
University of California, Berkeley

New Marine Products

William H. Fenical
Acting Director
Institute of Marine Resources
University of California
La Jolla, California

Education

Dale E. Ingmanson
Natural Science Department
San Diego State University

Ocean Engineering

William C. Webster
Naval Architecture
University of California, Berkeley

Aquaculture Industry Advisory Committee

Richard Glenn
Seafarms West
Carlsbad, California

George Lockwood
Hawaiian Abalone Farms
Kailua-Kona, Hawaii

John McMullen
Ab Lab
Civil Engineering Lab
Port Hueneme, California

Frank Oakes
The Abalone Farm
Cayucos, California

Anthonie M. Schuur
President, California
Aquaculture Association
Aquafuture, Inc.
Bakersfield, California

Frank Spenger, Jr.
Frank Spenger Company
Berkeley, California

Hugh W. Staton
Abalone Unlimited, Inc.
Guadalupe, California

F. Robert Studdert
San Rafael, California

Philip L. Wilson III
Managing Partner
Aquaculture Enterprises
Kailua-Kona, Hawaii

Seafood Industry Advisory Committee

Tod Ghio, Chairman
Ghio Seafood Products
San Diego, California

Maurice Camillo
J. J. Camillo Seafood Brokerage
San Diego, California

Robert Dean
International Pacific Seafood
South El Monte, California

Mike De Garimore
Central Coast Seafoods
Morro Bay, California

Tom Elliott
Washington Fish and Oyster Co.
San Francisco, California

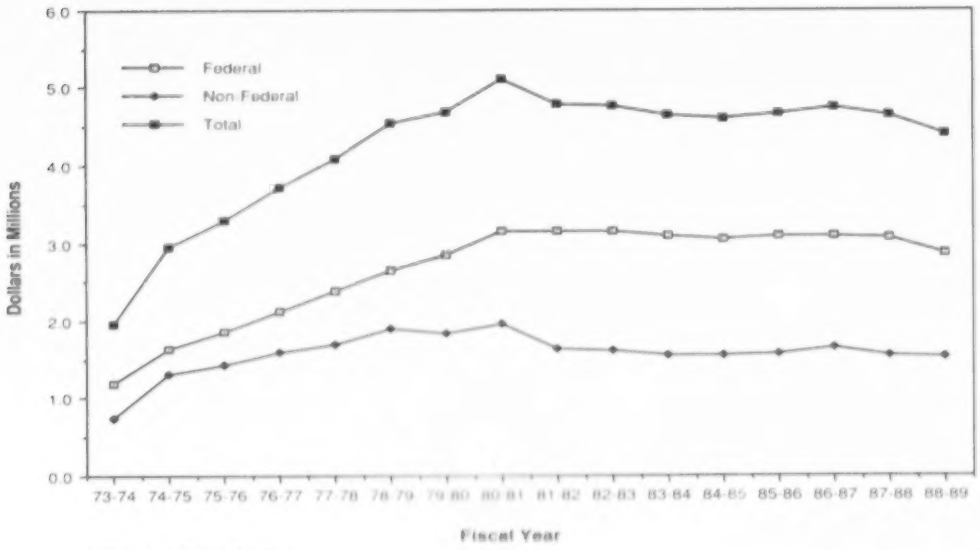
Frank Mason
San Diego, California

Bill Merry
W. R. Merry Seafood Co.
Los Angeles, California

Nick A. Vitalich
David Ptak (alternate)
Chesapeake Fish Company
San Diego, California

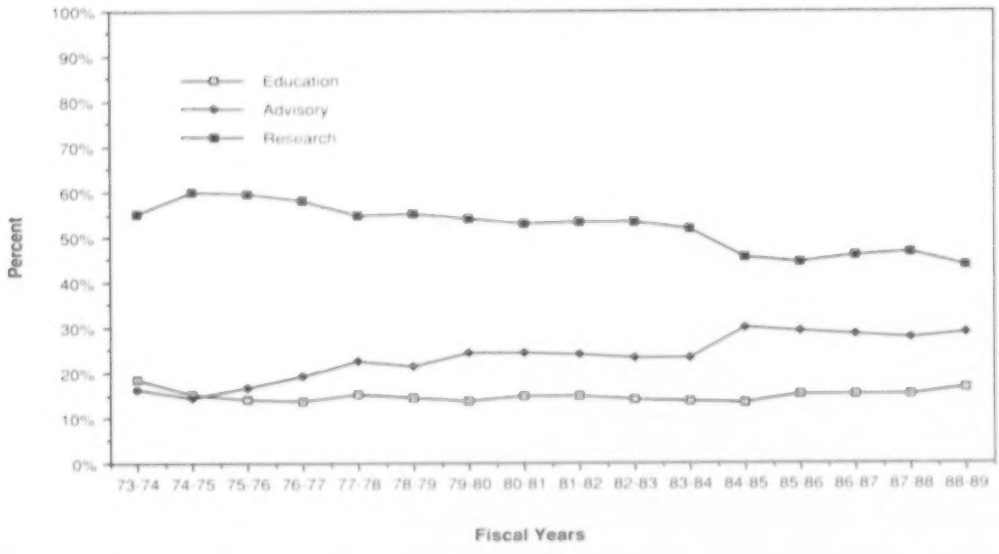
Fiscal and Administrative Data

Program Funding History
1973 - 1989



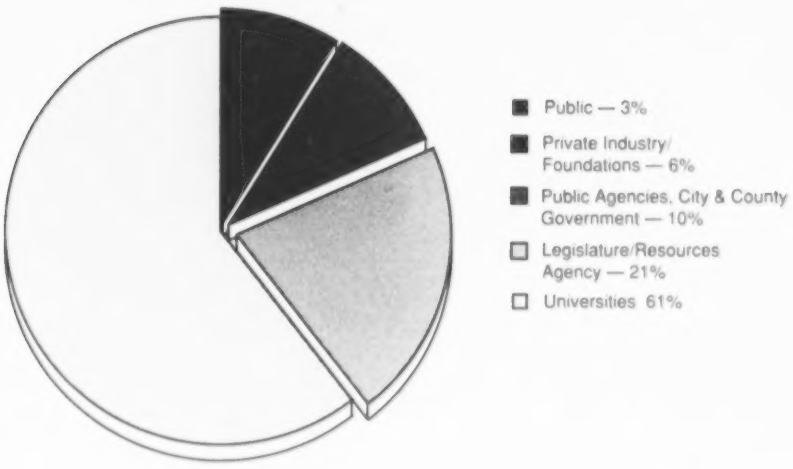
Excludes Passthrough Funds

Percentage Distribution of Sea Grant Funds*
for Advisory, Education and Research
1973-1974 Through 1988-1989

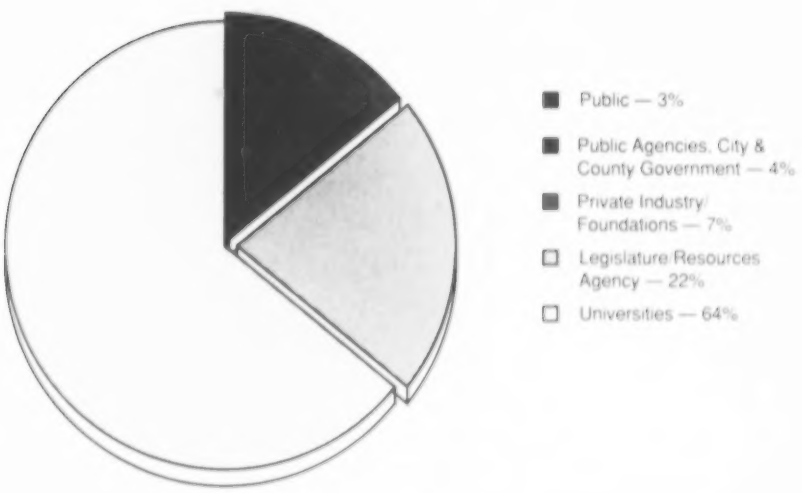


*National Office of Sea Grant and State Resources Agency Funds
Source: California Sea Grant College Program Institutional Proposal, Revised, Volume I

Sources of Matching Funds
1973/74 — 1979/80
$10,558,032

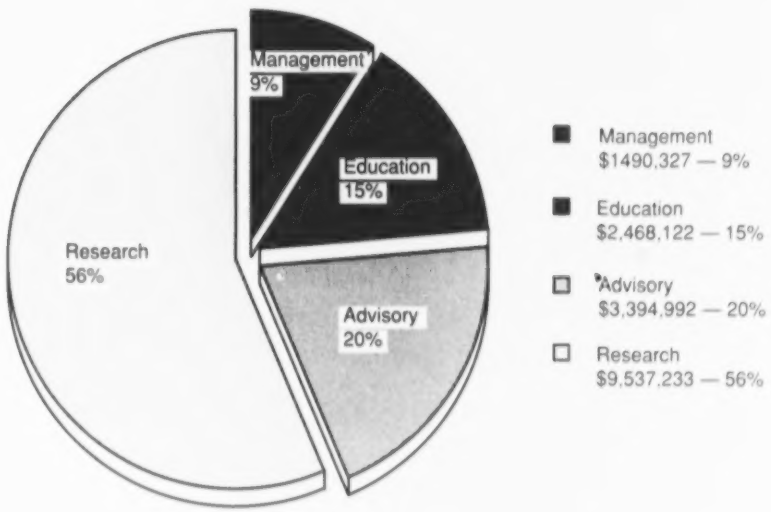

Public — 3%
Private Industry/ Foundations — 6%
Public Agencies, City & County Government — 10%
Legislature/Resources Agency — 21%
Universities 61%

Sources of Matching Funds
1980/81 — 1988/89
$14,665,642

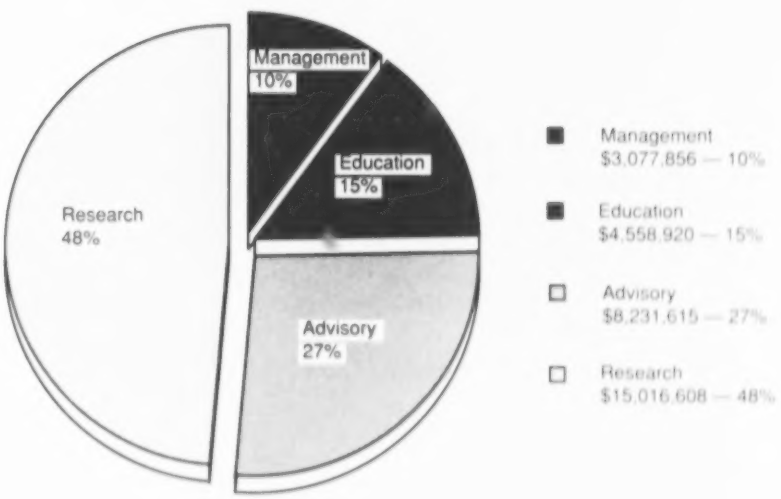

Public — 3%
Public Agencies, City & County Government — 4%
Private Industry/ Foundations — 7%
Legislature/Resources Agency — 22%
Universities — 64%

Total Matching Funds: $25,223,674
Source: California Sea Grant Program Institutional Proposal, Revised Volume I

Distribution of Funds* Among Program Areas
1973/74 — 1979/80
$16,890,674

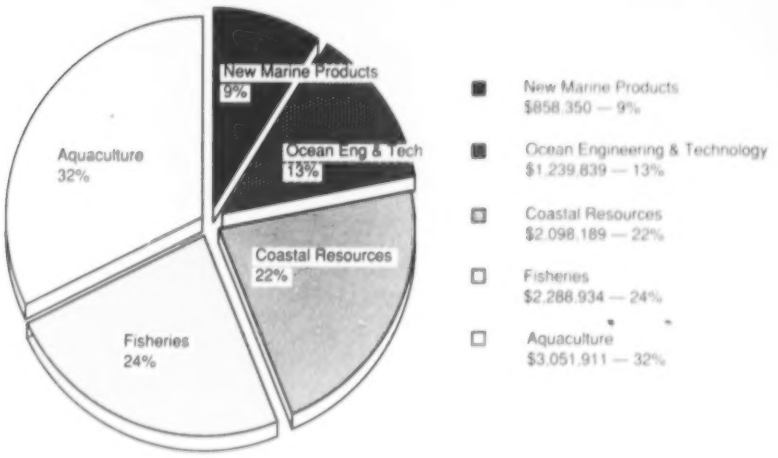


Distribution of Funds* Among Program Areas
1980/81 — 1988/89
$30,884,999

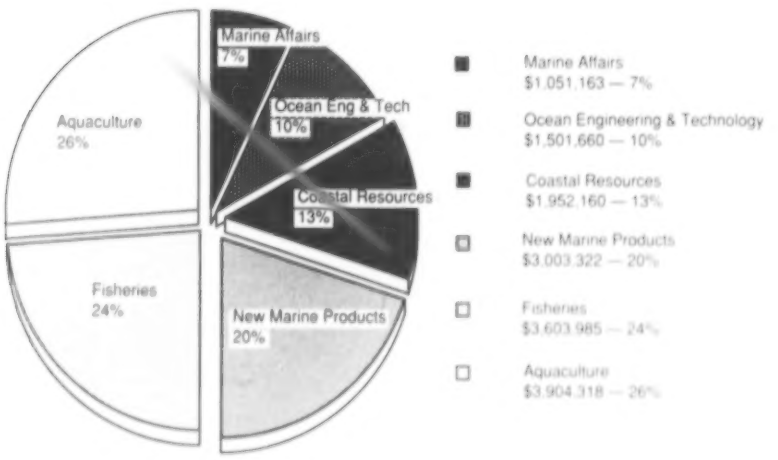


*National Office of Sea Grant and State Resources Agency Funds
Source: California Sea Grant College Program Institutional Proposal, Revised Volume I

Distribution of Research Funds* By Subject Area 1973/74 — 1979/80



Distribution of Research Funds* by Subject Area 1980/81 — 1988/89



*National Office of Sea Grant and State Resources Agency Funds
Source: California Sea Grant College Program Institutional Proposal, Volume I

NUMBER OF PROJECTS AND ASSOCIATED PERSONNEL*
1973 through 1989

	73-74	74-75	75-76	76-77	77-78	78-79	79-80	80-81	81-82	82-83	83-84	84-85	85-86	86-87	87-88	88-89
Individuals																
Faculty & Professional	85	134	128	171	183	186	183	181	125	143	189	192	180	145	112	107
Graduate Students	61	99	88	86	92	85	86	93	77	75	61	59	64	65	57	62
Undergraduates	11	51	21	16	41	35	26	22	16	19	17	18	15	11	12	12
Technicians	14	28	36	38	28	32	32	31	37	34	26	21	18	15	20	20
Clerical	25	38	38	40	41	44	79	71	54	54	54	50	47	39	32	25
Other	67	1	41	43	51	41	41	41	24	45	54	54	40	40	3	0
TOTAL	263	351	352	394	436	423	447	439	333	370	401	394	364	315	236	226
Full -Time Equivalents																
Research	36.73	71.64	80.50	81.34	74.27	72.32	70.76	61.72	49.55	50.78	42.40	38.83	35.05	27.48	28.48	23.88
Education	26.93	39.75	30.00	32.00	38.76	37.87	32.81	37.50	25.53	30.94	28.00	26.00	25.50	24.50	24.51	23.00
Advisory	11.44	15.72	17.46	20.54	25.36	24.98	27.33	28.20	21.02	25.64	25.27	31.12	28.40	23.55	20.65	18.65
Management	8.75	13.19	14.02	15.49	14.52	13.76	11.97	11.60	10.26	9.20	9.96	8.80	8.50	8.24	7.42	7.59
TOTAL	83.85	140.30	141.98	149.37	152.91	148.93	142.87	139.02	106.36	116.56	105.36	104.75	97.45	83.77	82.06	73.12
Research Projects (No.)	31	34	35	44	46	42	44	46	37	42	38	38	40	39	39	37
Research Projects (Aver. size)*	$21,323	$34,363	$37,621	$32,771	$32,974	$40,054	$39,776	$40,677	$48,167	$43,998	$41,078	$42,369	$38,976	$40,990	$41,813	$38,582

*California Sea Grant College Program
•National Office of Sea Grant and State Resources Agency funds
Source: California Sea Grant College Program Institutional Proposal, Revised Volume I

California's Sea Grant Institutions

Bodega Marine Laboratory
California Academy of Sciences
California Institute of Technology
California Maritime Academy
California Polytechnic University
California State University, Fresno
California State University, Hayward
California State University, Long Beach
California State University, Los Angeles
California State University, Northridge
Cerritos Community College
Claremont College
Coker College
El Camino Junior College
Foremost Research Center
Fullerton Community College
Highline College
Humboldt State University
Immaculate Heart College
Loyola Marymount University
Monterey Bay Aquarium
Moss Landing Marine Laboratories
Occidental College
Oceanic Society
Point Loma College
San Diego State University
San Francisco State University
San Jose State University
Santa Barbara Community College
Southern California Ocean Studies Consortium
Stanford University
University of Arizona
University of California, Berkeley
University of California, Davis
University of California, Irvine
University of California, Los Angeles
University of California, Riverside
University of California, San Diego
University of California, San Francisco
University of California, Santa Barbara
University of California, Santa Cruz
University of Nevada
University of San Diego
University of Southern California
University of the Pacific

Photo Credits
SIO photos, pp. 4, 6, 19, 41, 71
Los Angeles Times, p. 11
Gary Griggs, p. 20
UC Cooperative Extension, p. 25